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JOHN L. RICH
EDITOR

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THE BULLETIN

of the

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JOHN L. RICH, *Editor*

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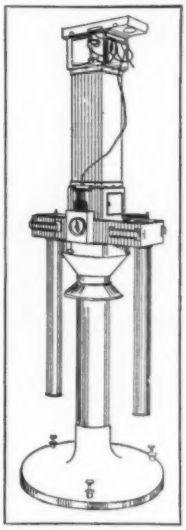

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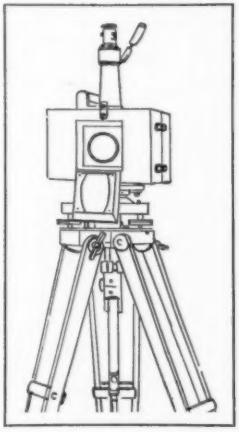

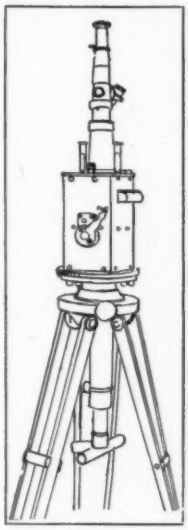

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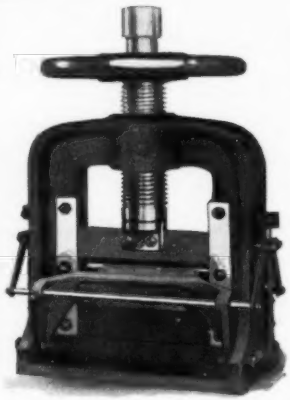

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THOMAS OIL FIELD, KAY COUNTY, OKLAHOMA[1]

STUART K. CLARK
Ponca City, Oklahoma

ABSTRACT

The Thomas oil field, located in the southwest corner of Kay County, Oklahoma, has produced approximately 3,000,000 barrels of oil from five horizons ranging from Pennsylvanian to Ordovician in age; but the major part of the production has come from the Wilcox sand (Ordovician).

Though the Thomas field does not rank as a major pool in point of production, it is of exceptional geological interest because of certain structural features of the pre-Pennsylvanian rocks and because of evidences which it yields as to the geological history of the area.

At the close of Mississippian time a small segment of sedimentary rocks was elevated approximately 1,000 feet above the adjacent area. Subsequent erosion removed about 400 feet of sediments from the top of this eminence, leaving a hill with the Wilcox sand (Ordovician) exposed at the crest and truncated surfaces of the "white lime" (Ordovician) Chattanooga shale (Devonian), and "Mississippi lime" (Mississippian) successively exposed on the flanks.

Later, Pennsylvanian and Permian sediments were deposited over the area, and this hill of resistant rocks impressed a structural likeness of its topographic form upon the successive layers of the younger rocks, with gradually diminishing intensity as the thickness of intervening sediments increased.

INTRODUCTION

The Thomas oil field is not a major pool from a production standpoint, but some features of the structure and geologic history of the area are of sufficient interest to make them worthy of record. The field is located in the center of T. 25 N., R. 2 W., Kay County, Oklahoma, about 6 miles northwest of the Tonkawa oil field.

HISTORY OF DEVELOPMENT

The discovery well of the Thomas field, Marland Oil Company's Thomas No. 1, was drilled on the strength of structural information

[1] Published by permission of the Marland Oil Company of Oklahoma.

obtained by core drilling. It was completed in May, 1924, as a 250-barrel well in sand encountered at a depth of 2,055 feet, which is hereafter called the Thomas sand.

The drilling campaign which followed this discovery was short-lived. Only two additional producers, Twin State Oil Company's Siler No. 1, in the NW. corner Sec. 22, and Carter Oil Company's Turk No. 1, in the NE. corner Sec. 21, were found at this horizon. The other drilling wells either missed the sand entirely or found it carrying water. All of them, except Marland's Thomas No. 2, in the SE. corner of SW. ¼ of SW. ¼ of Sec. 15, were shut down. It was drilled deeper, and in May, 1925, was completed as a 3,600-barrel well in the Wilcox sand. The top of the sand was found at 3,955 feet, and the well, as finally completed, penetrated the sand 91 feet.

A second drilling campaign was immediately begun. It resulted in the finding of eleven producing wells in the Wilcox sand, and three additional producing horizons. In the order of their discovery these horizons were: the chert at the top of the "Mississippi lime," with four producing wells; the 2,600-foot, or Turk, sand, with two wells; and a 1,900-foot sand with one well. The development of the field at the present time (March, 1926) is practically complete.

PRODUCTION

The Thomas field has produced to date 3,000,000 barrels of oil. Its present daily average is 7,000 barrels, and its ultimate total production is estimated at approximately 4,500,000 barrels.

The major portion of the oil has come from the Wilcox sand. The initial production of the wells in this horizon ranged as high as 6,500 barrels per day. The maximum initial production of wells producing from the chert at the top of the "Mississippi lime" was about 250 barrels. The Turk-sand wells produced about 75 barrels per day. The largest initial production from the Thomas sand was 350 barrels. The one well in the 1,900-foot sand started at 400 barrels a day but declined very rapidly.

The oil produced is the high-gravity (42°–44° Baumé) green oil which is characteristic of this general district. Open flows of from 10,000,000 to 30,000,000 cubic feet of gas were encountered by several wells in a sandy lime in the Permian rocks at a depth of 1,200 feet.

STRATIGRAPHY

The surface rocks in this area are the Wellington shales of Permian age. The sequence and thickness of the formations underlying the area and the stratigraphic position of the various oil-producing horizons are shown graphically in the accompanying geologic section (fig. 1). The thicknesses shown in this section are the maximum encountered, and consequently do not indicate the depths at which the deeper horizons are found on the top of the structure. In the order in which they are encountered by the drill, the strata that underlie the area are described in the following paragraphs.

Permian.—Rocks of Permian age are found from the surface to a depth of 1,200 to 1,300 feet. They include a series of alternating gray and red shales about 450 feet thick at the top; a series of thin gypsum or anhydrite beds (logged as limestone by the drillers) separated by gray shales, with a total thickness of 150 feet; and a series of alternating limestones and red shales about 600 feet thick, with the Herington limestone at the top and the Neva limestone at the bottom.

The base of the "red beds" practically coincides with the base of the Permian.

Pennsylvanian.—The Pennsylvanian system includes a maximum thickness of 2,800 feet of blue and gray shales, limestones, and sandstones. The prominent limestones include the Foraker, Pawhuska, Oread, and the "Oswego–Big Lime" group. The most prominent sandstones include the Hoover sand series, the Endicott sand series, and the Layton sand. The Tonkawa sand is represented only by a sandy shale zone over the top of the fold. Thin beds of red rock are found at the top of the Endicott sand zone and a short distance above the base of the Pennsylvanian.

Three of the producing horizons of the field lie in the Pennsylvanian. They are all sandstones. The 1,900-foot and Thomas sands are separated by an interval of less than 100 feet and occur immediately above the Pawhuska lime. The Turk, or 2,600-foot, sand is the equivalent of the Upper Endicott sand of the Tonkawa field.

The Cherokee shales, which constitute the basal member of the Pennsylvanian system, vary greatly in thickness, as indicated by the accompanying cross-sections (Figs. 2 and 3). On the flanks of the

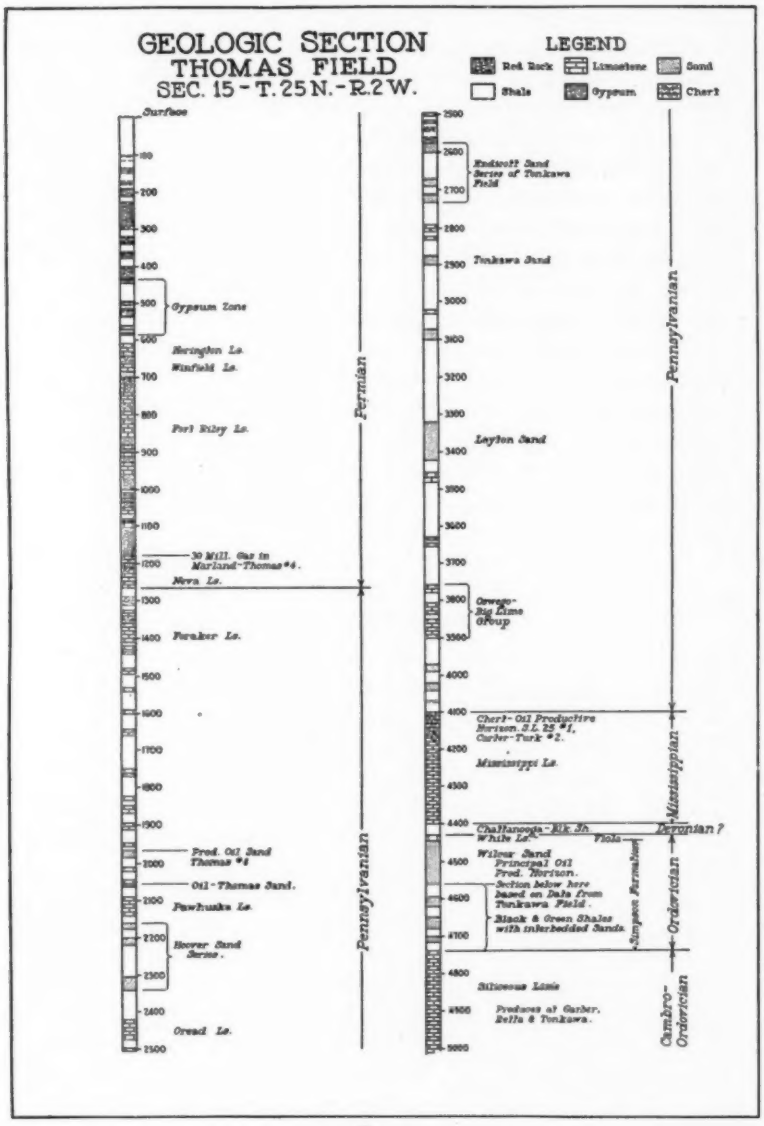

GEOLOGIC SECTION
THOMAS FIELD
SEC. 15 - T. 25 N. - R. 2 W.
LEGEND
Red Rock
Limestone
Sand
Shale
Gypsum
Chert
Surface
Gypsum Zone
Herington Ls.
Winfield Ls.
Fort Riley Ls.
30 Mill. Gas in Marland-Thomas #4.
Nova Ls.
Funaker Ls.
Prod. Oil Sand Thomas #1
Oil - Thomas Sand.
Pawhuska Ls.
Hoover Sand Horne.
Oread Ls.
Permian
Pennsylvanian
Endicott Sand Series of Tonkawa Field
Tonkawa Sand
Layton Sand
Oswego-Big Lime Group
Chert - Oil Productive Horizon. S.L. 25 #1, Carter-Turk #2.
Mississippi Ls.
Chattanooga - Blk. Sh.
White Ls.
Viola
Wilcox Sand Principal Oil Prod. Horizon.
Section below here based on Data from Tonkawa Field.
Black & Green Shales with interbedded Sands.
Simpson Formation
Siliceous Lime
Produces at Garber, Bella & Tonkawa.
Pennsylvanian
Mississippian
Devonian ?
Ordovician
Cambro-Ordovician

FIG. 1

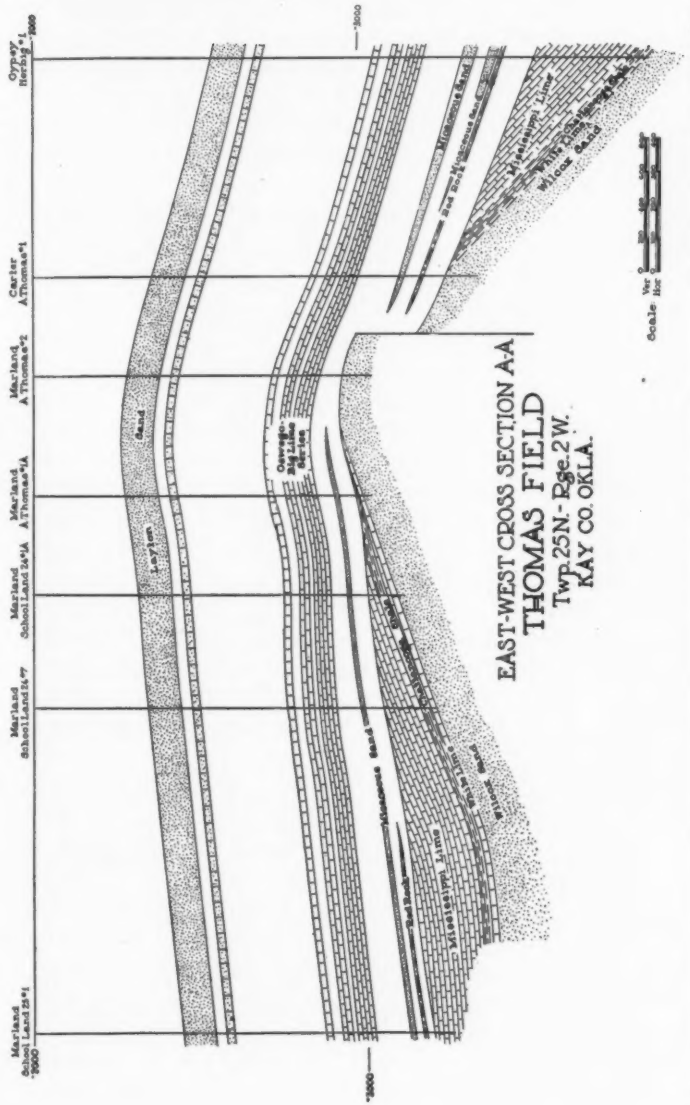

EAST-WEST CROSS SECTION A-A
THOMAS FIELD
Twp. 25N - Rge. 2W.
KAY CO. OKLA.
Scale
Ver.
Hor.
Marland School Land 15-1
Marland School Land 15-4
Marland School Land 15-4A
Marland A Thomas-1A
Marland A Thomas-2
Carter A Thomas-1
Osage Sand
Layton
Mississippi Lime
White Chert
Wilcox Sand

FIG 2

fold two distinct beds of fine-grained, shaly, micaceous sand are found in the Cherokee. These beds are usually ignored or simply logged as "shells" by the drillers, but they are of considerable assistance to the geologist who is following the progress of a drilling well, since they can readily be distinguished from the sands of the Simpson formation, and their presence furnishes conclusive evidence that a well is still in the Pennsylvanian.

Mississippian.—The Mississippian system is represented by the "Mississippi lime," with a maximum thickness of 300 feet. It varies from a gray to dark brown or black cherty limestone, with a variable thickness of residual chert at the top.

On the west flank of the "structure," where this chert bed attains its greatest thickness, it serves as the reservoir rock from which Carter Oil Company's Turk No. 2 and No. 4, Wentz Oil Corporation's Thomas No. 2, all in Sec. 21, and Marland Oil Company's School Land No. 25, well No. 1, in Sec. 16, are producing.

Devonian.—The Chattanooga shale, a black carbonaceous shale containing a considerable amount of iron pyrites, has in the past been referred to the Devonian system, but some recent workers are inclined to place it in the Mississippian. It has a uniform thickness of about 30 feet.

Ordovician and Cambro-Ordovician.—Rocks of strictly Ordovician age in this area include the "white lime" and the Simpson formation. As the name implies, the "white lime" is a white to putty-colored limestone about 15 feet thick, which is believed to be the equivalent of the upper part of the Viola limestone.

Though the entire thickness of the Simpson formation has not been penetrated in the Thomas field, from data in nearby areas it is believed to be approximately 300 feet thick. The top member of the Simpson is the Wilcox sand, a practically pure quartz sand made up largely of well-rounded and frosted sand grains. This sand is readily recognizable because of its purity, the character of its grains, the presence of scattered thin green shale partings, and the total absence of the small flakes of mica which are characteristic of the Lower Pennsylvanian sands.

In the Tonkawa field the thickness of the Wilcox member is about 120 feet. The remainder of the Simpson section there consists

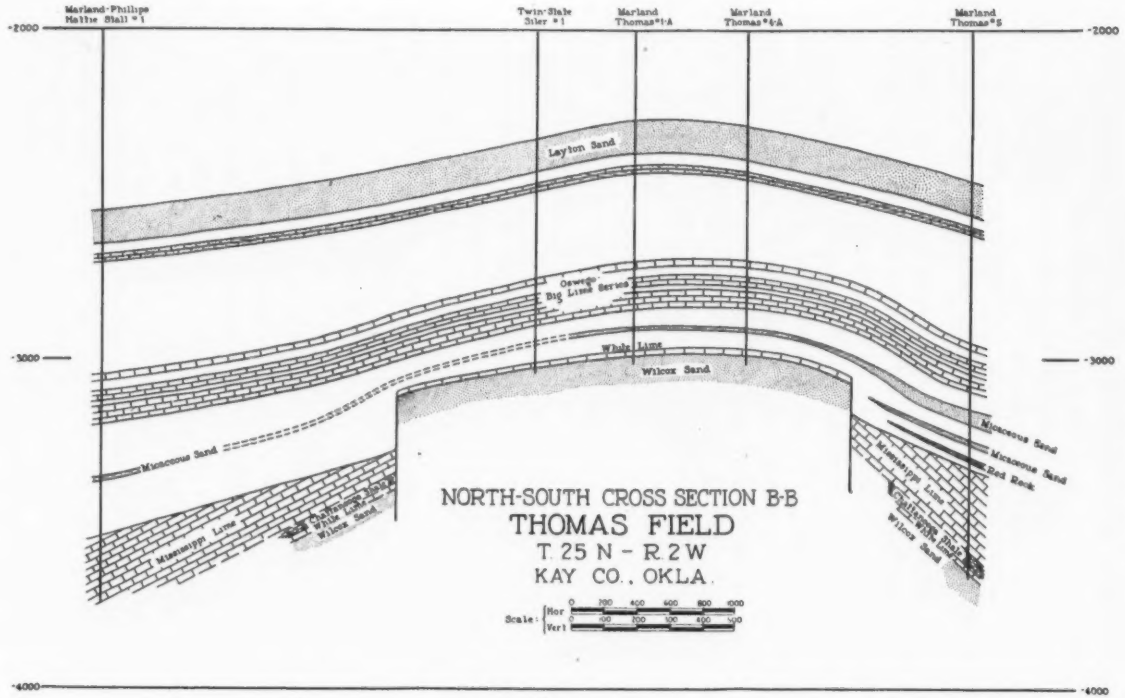

Marland-Phillips Maltie Stall #1
Twin-Slate Siler #1
Marland Thomas #1-A
Marland Thomas #4-A
Marland Thomas #5
-2000
-3000
-4000
Layton Sand
Osage
Big Lime Series
Whale Lime
Wilcox Sand
Micaceous Sand
Red Rock
Mississippi Lime
Chattanooga Shale
NORTH-SOUTH CROSS SECTION B-B
THOMAS FIELD
T. 25 N - R. 2 W
KAY CO., OKLA.
Scale: Hor 0 200 400 600 800 1000
Vert 0 100 200 300 400 500

FIG. 3

of alternating beds of black and green shale and thinner beds of sandstone similar in character to the Wilcox sand.

Below the Simpson formation is an unknown thickness of the "siliceous lime" of Cambro-Ordovician age.

STRUCTURE AND GEOLOGIC HISTORY

The Thomas field lies on a major line of folding passing through the Blackwell, Otstot, Retta, and Garber fields. The structure and geologic history of all these fields are closely related.

From the evidence now available it appears that the first local structural movement affecting this area came at the close of Mississippian time. As a result of this movement a wedge-shaped segment of the pre-Pennsylvanian rocks was elevated approximately 1,000 feet above the adjoining area. The structure developed by this movement is indicated on the structure map by contours drawn on the top of the "white lime" (Fig. 4).

During, and subsequent to, the elevation of this wedge, erosion altered its topography by removing from its crest between 300 and 400 feet of sediments, including all the "Mississippi lime," the Chattanooga shale, the "white lime," and part of the Wilcox sand, thus leaving an inlier of Wilcox sand exposed at the top and the truncated surfaces of the "white lime," Chattanooga shale, and "Mississippi lime" successively exposed on the flanks. Beds of residual chert, presumably resulting from the concentration of the silica originally present in the eroded portion of the "Mississippi lime," accumulated on the slopes of the hill.

The original form of the hill was further modified by a reduction in the height of the fault scarps; that is, the areas immediately adjacent to and on the upthrown sides of the faults, being more exposed, were reduced more by erosion. This is strikingly illustrated by a comparison between Marland Oil Company's Turk No. 1, NE. corner of SE. $\frac{1}{4}$ of NE. $\frac{1}{4}$ of Sec. 21, and Carter's Turk No. 4, NW. corner of NE. $\frac{1}{4}$ of NE. $\frac{1}{4}$ of Sec. 21. The structure on the top of the "white lime" shows Marland's Turk No. 1 to be only about 25 feet lower than Carter's Turk No. 4, whereas the top of the "Mississippi lime" in Marland's Turk No. 1 is about 100 feet lower than the top of the "Mississippi lime" in Carter's Turk No. 1.

The topography and areal geology of this pre-Pennsylvanian hill, as it would now be if the overlying strata were removed, are shown graphically by the accompanying map (Fig. 5). The point should be emphasized that this is not a structure map, since the contours do not depict the attitude of one specific bed, such as the "white lime" or the Layton sand. It is essentially a topographic map because it

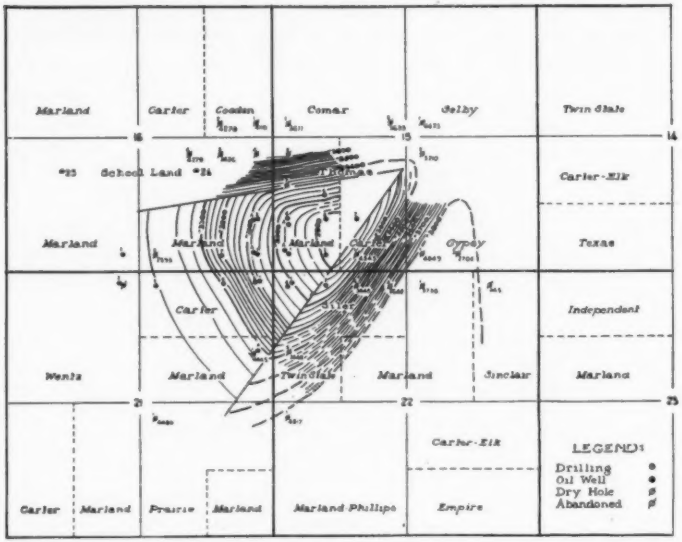


FIG. 4.—Structure contours; top, white lime. Thomas field, T. 25 N., R. 2 W., Kay County, Oklahoma (contour interval, 25').

pictures the eroded surface upon which the Pennsylvanian beds were deposited. The areal geology of this surface comprises an inlier of Wilcox sand encircled by successive exposures of the "white lime," Chattanooga shale, and "Mississippi lime." This map departs from conventional topographic methods in one respect, namely, the fault lines shown on the structure map contoured on the top of the "white lime" are retained in this map to show the fault scarps that remained at the close of the period of erosion. It was felt that this departure was justifiable because of the intimate relation between the structure and topographic maps in this instance.

The two cross-sections, A–A and B–B (Figs. 2 and 3), also show, in vertical section, the relation between the pre-Pennsylvanian structure and topography and give an accurate impression of the amount of material removed by erosion.

Following this period of erosion the pre-Pennsylvanian hill was gradually submerged and eventually buried under several thousand feet of sedimentary rocks. For a time, however, the top of the hill

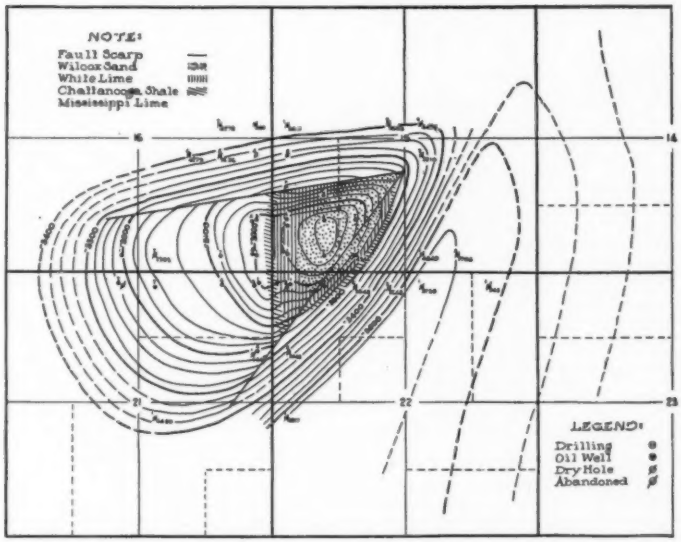


FIG. 5.—Topography and areal geology of pre-Pennsylvanian surface. Thomas field, T. 25 N., R. 2 W., Kay County, Oklahoma (contour interval, 25′).

formed an island in the Pennsylvanian sea. This is indicated by the fact that the first beds deposited on the flanks of the hill do not extend over its crest; and also by the fact that the crest of the hill contributed some material in the form of Wilcox sand grains and small fragments of green shale to the earliest Pennsylvanian bed, the shale between the red rock and the top of the "Mississippi lime."

But even after this hill was completely buried its presence influenced the entire subsequent geologic history of the area. In fact, the structure of the younger rocks is simply a modified likeness of

the topography of the buried hill. The degree of likeness decreases steadily upward, that is, the folding of the successive beds becomes less pronounced, the dips becoming more and more gentle as the thickness of intervening strata increases. These features are illustrated by accompanying maps (Figs. 6 and 7), showing the structure of the Layton sand and the Pawhuska lime, respectively.

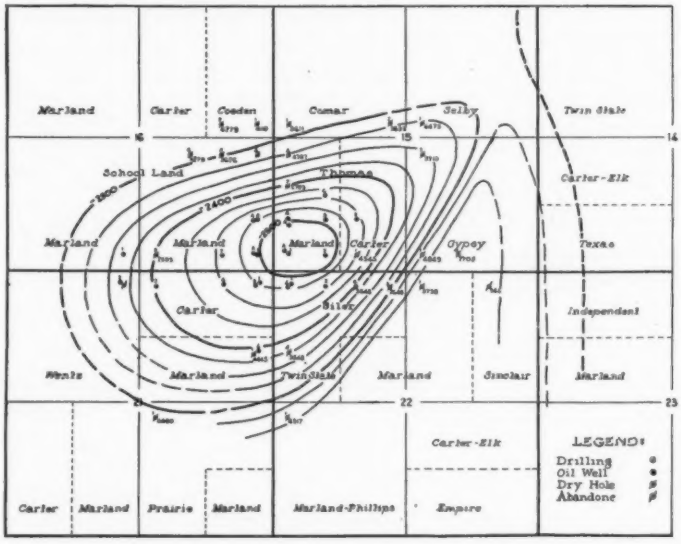


FIG. 6.—Structure contours; top, Layton sand. Thomas field, T. 25 N., R. 2 W., Kay County, Oklahoma (contour interval, 25′).

In conclusion, it seems desirable to summarize the evidence which supports the interpretation of the pre-Pennsylvanian structure presented in this paper, namely, that the principal structural feature is not a true dome, but an elevated wedge-shaped block, faulted on both sides.

1. The brittle character of the rocks involved makes it almost inconceivable that a dome of such small area could be elevated to such a height without faulting. The "siliceous lime" which underlies the entire area and presumably extends down to the basement granite contains no shale beds of appreciable thickness. From the Simp-

son section, found in the Tonkawa field, it seems safe to assume that the total thickness of shale, including the Chattanooga, below the top of the "Mississippi lime" does not greatly exceed 150 feet.

2. The lack of any pronounced flexure of the beds within the area of this wedge also argues against the existence of an unfaulted fold. For instance, in the east-west cross-section, A–A (Fig. 2), the

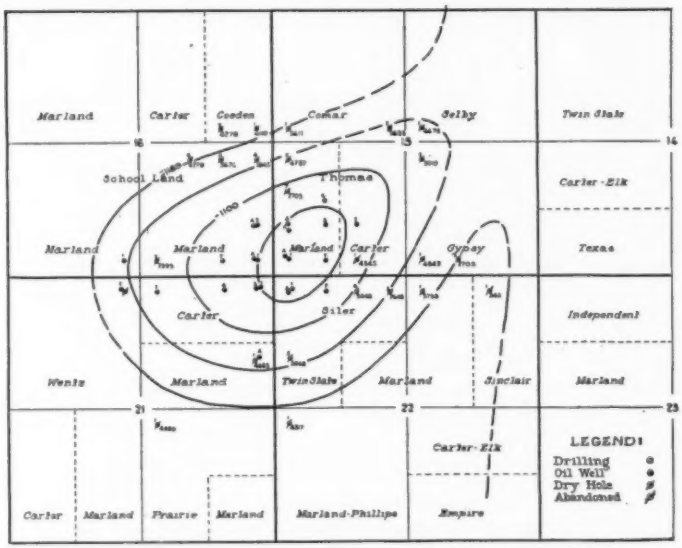


FIG. 7.—Structure contours; top, Pawhuska lime. Thomas field, T. 25 N., R. 2 W., Kay County, Oklahoma (contour interval, 25′).

points at which the top of the Wilcox sand was encountered in Marland Oil Company's wells, School Land No. 24, No. 7 and No. 1A, and Thomas No. 1A, fall in a straight line, showing no curvature whatever. Similarly, in the north-south cross-section, B–B (Fig. 3), the top of this same sand shows only a very slight flexure from the Twin State's Siler No. 4 to Marland's Thomas No. 4. The degree of curvature shown here is entirely inconsistent with the dip which must be postulated if it is assumed that no fault exists between Thomas No. 4 and Thomas No. 5.

3. The fault scarp revealed by cross-section A–A (Fig. 2), between Marland Oil Company's Thomas No. 2 and Carter Oil Company's Thomas No. 1, as indicated by the break in the otherwise smooth curve of the pre-Pennsylvanian eroded surface and by the abrupt change in the Cherokee shale section, affords conclusive evidence of the existence of this fault.

4. The presence of dolomitic cementing material in the entire thickness of Wilcox sand penetrated in wells adjacent to the supposed fault planes and its absence in the other wells furnishes strong evidence of an avenue, such as a fault plane, affording a vertical circulation of water from the "siliceous lime" to the surface during the erosion period, since the "siliceous lime" is the only normally dolomitic horizon in the rocks involved.

5. The finding of a "hole full" of hot sulphur water in the "Mississippi lime" in Marland's Thomas No. 5 suggests the probability that nearby faulting has either thrown the "siliceous lime" in contact with the "Mississippi lime" or has at least provided the fissures through which this water reached its present position, since the sulphur water is indigenous to the "siliceous lime," but is normally unknown in the "Mississippi lime."

DISCUSSION

W. E. WRATHER: Mr. Clark is to be commended for the excellence of his maps and charts, which are admirably adapted to illustrate an oral presentation of a paper on the convention floor.

W. VAN DER GRACHT: This paper gives an excellent method of interpreting these pre-Pennsylvanian structures and what happened to them afterward by erosion before they were covered by the Pennsylvanian, and how, ultimately, the latter beds were deformed. This paper shows how the still puzzling problems concerning many other mid-continent structures of this kind should be solved. I hope that many geologists will imitate Mr. Clark's method, which in this case yielded such very suggestive, and apparently very well-founded, results.

DIAMOND DRILLS AND DIAMOND-DRILL EQUIPMENT FOR OIL STRUCTURE INVESTIGATION

ROBERT DAVIS LONGYEAR
Minneapolis, Minnesota

ABSTRACT

This paper deals briefly with the types of drills and equipment used in the exploration of prospective oil lands in such a way as to enable a prospective purchaser to form some idea of the practices that have been found by others to be best adapted for the particular requirements of oil structure investigation.

INTRODUCTION

Only a few years ago the diamond core drill was a matter of little interest to the oil producer and explorer. Now, as a necessary instrument for the exploration of prospective oil lands, it has achieved an importance exceeding the early predictions of its most enthusiastic supporters. The speed with which the diamond drill gains its objective and then moves on to the next job has enabled a comparatively small number of outfits to "make so much hole" that the total amount of drilling completed during the last twelve months probably lies fairly close to 750,000 feet.

NUMBER OF DRILLS IN OPERATION

According to information available, fifteen oil companies in the United States own and operate fifty-two diamond drills for the purpose of investigating structure conditions. In addition to these a certain amount of this work is being carried on by contractors, while other diamond drills are being employed in making wild-cat tests and in coring oil sands in producing fields. Of the fifty-two drills referred to above, eighteen are driven by steam engines, and thirty-four, by gas engines. Some of the steam drills are soon to be made over into gas-driven drills. Five drills have a capacity of approximately 2,000 feet of 2-inch core, forty-three drills have a capacity of about 1,000 feet, and four are light outfits for shallow work.

THE DRILL OUTFIT

The principle of operation of the diamond drill is, in general, the same as that of rotary drills. In fact, the rotary drill was developed in the Gulf Coast country from an old type of diamond drill manufactured in Holland. The diamond drill outfits used for structure drilling have no rotary table; the drill rods (or stem) are rotated by a drive rod through which they pass and to which they are firmly held by a chuck. The drive rod in turn is rotated through a pair of bevel gears by the main power shaft. A hydraulic cylinder controls the feed, and the drive rod is suspended from a ball-bearing on the upper end of the piston rod. By means of valves leading from the pump to the hydraulic cylinder the operator can place any desired pressure upon the bit or advance the feed downward at any required rate. At the end of each stroke of the piston the rods are rechucked and another run is made.

FIG. 1.—Core drilling in northern Oklahoma

The first diamond drills purchased by the oil companies were steam-driven drills, but gas-driven drills have been found in general to be more desirable for this class of work. Boiler trouble, a very serious matter in most prospective oil territory, is eliminated, and for holes up to 700 or 800 feet in depth the saving in moving from hole to hole is an appreciable item of economy.

Figure 2 illustrates an assembly of diamond drill, duplex pump, and Fordson tractor gas engine. The capacity is about 1,000 feet of 2-inch core. Most of the gas drills are of this general arrange-

ment, although a few units have been built with a self-propelling mechanism. This feature has certain advantages, which are somewhat offset by the disadvantage of increased weight and number of moving parts.

The hoist is of the internal geared type, driven from the main shaft. One manufacturer includes with the outfit a cathead for raising the tripod, handling casing, and pulling the drill out of mud

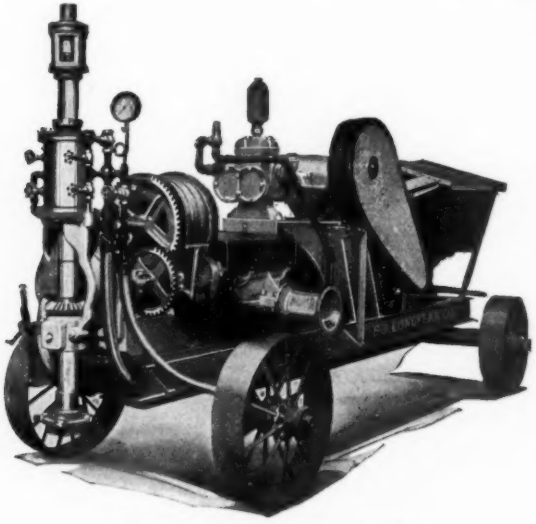


FIG. 2.—Gas-driven diamond drill

holes. Connections to the gas engine are of various types and will not be discussed in detail.

The $3\frac{1}{2}\times5$ Gardner pump is driven from the power take-off of the Fordson motor, a by-pass controlling the volume of water. Mud fluid is necessary for drilling, but since the smallest mud pump now on the market is too large for this type of drill, the standard water pump is used. A $3\frac{1}{2}\times5$ mud pump is now being placed on the market. One oil company eliminates the pump entirely from the drill mounting, and installs the pump on the front end of a separate Fordson tractor. Driving the pump with a separate motor has the

advantage of allowing greater variation in the pump speed and of decreasing the risk of a stuck bit in case the gas engine should stall. The disadvantage is the extra cost of running a second gas engine. A special assembly is now being experimented with in Texas, consisting of a diamond drill, Waukesha gas engine, and two pumps, one for the hydraulic feed and one for the mud. The pumps are controlled by variable speed belt drive.

The gas outfits first manufactured had an electric lighting system attached. With proper care, this gives good service, but under rough usage most of them have been unsatisfactory. One manufacturer has discontinued installing the electric lighting plant as standard equipment.

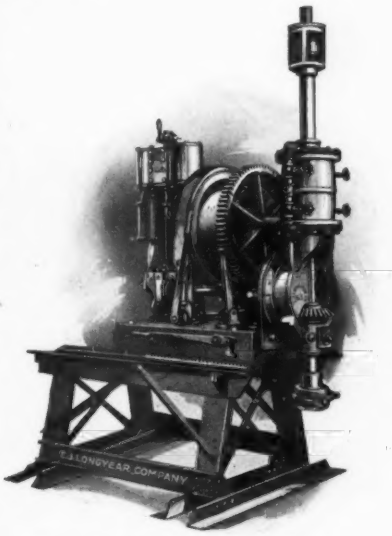


FIG. 3.—Steam-driven diamond drill

Figure 3 illustrates a steam drill of a capacity of approximately 2,000 feet of 2-inch core. The steam drill can be mounted on a truck to make it more readily portable. One oil company has made over a steam drill of this general capacity into a gas-driven drill, using a Climax engine for the motive power.

The characteristic part of the diamond drill is, of course, the diamond bit, which is an annular piece of soft steel set with four or more carbons or black diamonds. The diameter of core taken in oil structure work is 2 inches, and is shown as size "N." The hole drilled is about $2\frac{1}{16}$ inches in diameter. Double tube core barrels of the ball-bearing type are usually used, although certain formations are cored satisfactorily with the single-tube core barrel. The core is held in the core barrel with a split ring core lifter.

The drill rods have an outside diameter of $2\frac{3}{8}$ inches. They are

made in exactly 10-foot lengths, to minimize errors in measurements of depth, and are usually hoisted and lowered in twenty-foot "pulls." Being flush-jointed, they cannot be handled with elevators, but are raised and lowered with a hoisting plug which is screwed into the upper end of the rod. The rods are held by two jaws of the safety clamp which rests on the platform and is operated by foot. The threads are square, four to the inch, and the joints can be made and broken with an ordinary pipe wrench.

The threads and dimensions of all diamond-drill equipment such as drill rods, core barrels, and bits have been standardized by the manufacturers. This fact is greatly appreciated by the users, as the various makes are thus interchangeable.

Very little casing is used. A joint or two of $4\frac{1}{2}$-inch, $4\frac{3}{4}$-inch, or 5-inch surface conductor is sometimes desirable. Caving formations may make is necessary to drill the upper part of the hole large enough to admit a 3-inch casing. It is sometimes necessary to ream the hole already drilled in order to shut off cave. The casing used is 3-inch pipe or tubing. It must not be heavier than 8 pounds to the foot, or the inside diameter will be too small to admit the diamond bit. Diamond-drill flush-joint casing is desirable if much reaming in hard formation is necessary, but for ordinary purposes the pipe is satisfactory and more economical.

Fishtail bits are extensively used, not only for reaming the hole for casing, but also to take advantage of the more rapid drilling progress in soft formations in which a core is not desired. Three sizes of fishtail bits are standard: 6-inch, $4\frac{1}{4}$ inch, and $2\frac{7}{8}$-inch. The 6-inch bit is used only for sinking the surface conductor. The $4\frac{1}{4}$-inch fishtail bit is used in drilling the upper portion of the hole where core is not desired and where it may be necessary to use casing. It is also used for reaming the "N" hole to a size large enough for the 3-inch casing, for this purpose sometimes being dressed to a point. The $2\frac{7}{8}$-inch fishtail bit is used alternately with the "N" diamond bit and is dressed to a gauge that will permit either bit to follow in the hole made by the other. The usual practice now is to face the cutting edge of the fishtail bit with stellite, stoodite, or other hard alloy. The process requires the bit first to be dressed in the usual manner,

but slightly under gauge. The alloy is then built up upon the bit with an acetylene torch, after which it is ground to a sharp cutting edge with proper gauge. This use of the alloy has effected large economies in drilling.

The derrick consists of a tripod of three poles approximately 35 feet long. A shelter, made in knock-down sections, is provided as a protection against the weather. This may house the entire outfit or simply inclose the drilling end (Fig. 1).

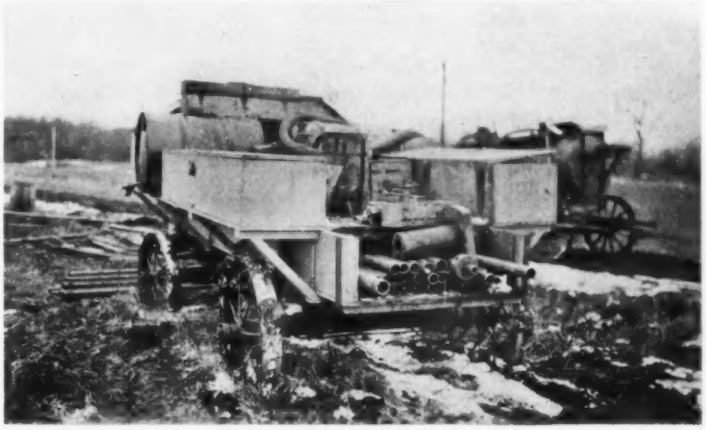


FIG. 4.—"Junk wagon"

A tank for hauling water is necessary and a tractor may be desirable for moving the outfit and digging the sump. A light automobile truck is usually supplied with each drilling unit or with each pair of drills. A "junk wagon" (Fig. 4) designed so as to hold drill rods, miscellaneous tools, and gasoline barrels, materially increases the efficiency of the crew. It not only saves loading and unloading time, but in addition the driller always knows just where to find the article he desires.

SELECTING THE PROPER EQUIPMENT

In Table I is given a suggested list of equipment for structure core drill work. This list is not complete, but contains sufficient ma-

TABLE I

LIST OF DIAMOND DRILL EQUIPMENT FOR OIL STRUCTURE INVESTIGATION

1. *Material to be purchased from diamond-drill manufacturer:*

- 1 Diamond drill complete with gas engine and pump;
- 500 feet (more or less) "N" drill rods
- 1 "N" water swivel
- 1 "N" hoisting plug
- 1 "N" lifting bail
- 1 "N" safety clamp with jaws
- 1 5-foot "N" drill rod
- 2 10-foot "N" double tube core barrels
- 1 set Parmalee wrenches for double tube core barrel
- 1 10-foot "N" single tube core barrel
- 1 20-inch "N" single tube core barrel
- 1 "N" guide rod with 1-foot drill rod
- 1 tripod clevis and bolt
- 1 24 inch sheave wheel with guard
- 1 set diamond setting tools
  - 1 "N" setting block
  - 1 "N" setting ring
  - 1 bench vise
  - 1 breast drill
  - 1 setting hammer
  - 1 pair dividers
  - 1 pair inside calipers
  - 1 pair outside calipers
  - 12 assorted chisels and punches
  - 10 assorted twist drills
  - 1 hacksaw frame
  - 12 hacksaw blades
- 1 25-foot by 1-inch 5-ply hose and connections
- 1 12-foot by 1-inch 5-ply hose and connections
- 1 lot assorted packing, waste, valves, pipe, and fittings
- 1 5-foot drip hose
- 24 "N" blank bits, double tube
- 12 "N" core lifters
- 4 "N" core shells, S.T. to D.T.
- 1 "N" cross-chopping bit
- 1 "N" rod to 3-inch pipe connection
- 1 drive block, 350-pound
- 1 "N" R. H. rod tap
- 1 "N" R. H. coupling tap

1 "N" R. H. rod spear
1 3-inch R. H. casing tap
6 $2\frac{7}{8}$-inch fishtail bits with "N" connections
6 $4\frac{1}{4}$-inch fishtail bits with "N" connections
2 6-inch fishtail bits with "N" connections

2. *Material to be purchased from diamond-drill manufacturer if reaming in hard formation is necessary:*

200 feet (more or less) "N" flush casing
1 "N" reaming barrel complete
4 "N" reaming bits
1 "N" rod to "N" casing connection

3. *Material to be purchased directly from carbon importer or from diamond-drill manufacturer:*

8 (or more) carbons (black diamonds), weighing from 2 to 5 carats each, at $100.00 to $150.00 per carat

4. *Material to be purchased locally or from diamond-drill manufacturer:*

A. Casing and Casing Equipment

50 feet (more or less) $4\frac{1}{2}$-inch, $4\frac{3}{4}$-inch, or 5-inch pipe or casing, including short matching pieces
200 feet (more or less) 3-inch pipe or tubing, including short matching pieces
1 pair $4\frac{1}{2}$-inch ($4\frac{3}{4}$- or 5-inch) casing clamps
1 pair 3-inch casing clamps
1 $4\frac{1}{2}$-inch ($4\frac{3}{4}$- or 5-inch) drive head
1 3-inch drive head
1 3-inch to $4\frac{1}{2}$-inch ($4\frac{3}{4}$- or 5-inch) reducer
1 $4\frac{1}{4}$-inch rock bit for reaming 3-inch casing through hard rock

B. Accessory Equipment

3 telephone poles for tripod, 35 feet long, 10- or 12-inch bottom
1 drill shanty in knock-down sections; sills and lumber for floor and scaffold; core boxes
1 wagon or light auto truck
1 tractor for hauling water and moving drill outfit
1 8- to 12-barrel water tank
1 junk wagon with compartments for drill rods, tools, etc.
1 hand pump
1 drag scraper for digging sump
1 plow
1 stove for drill shanty
1 water heater for cold weather

C. Small Tools

1 tool box
1 pair boomers
2 15-foot chains
1 endless chain
1 ⅜-inch×6-foot chain, with hook and ring
2 5-gallon oil cans
1 hand oiler
1 tin funnel
1 14-quart bucket
1 single bit axe
1 2-foot wrecking bar
2 crowbars
1 12-inch monkey wrench
6 10-inch flat files
1 2-pound machinist hammer
1 claw hammer
1 rig-builder's hatchet
1 screwdriver
1 pair pliers
1 emery wheel
1 12-inch spirit level
2 cold chisels
1 handsaw
1 No. 34 chain tongs
1 No. 33½ chain tongs
1 36-inch pipe wrench
2 24-inch pipe wrenches
2 18-inch pipe wrenches
1 wire thread brush
1 pipe vise
1 1-inch to 2-inch pipe cutter
1 ½-inch to 2-inch pipe stock and dies
1 8 pound sledge hammer
1 8-inch single block for 1-inch rope
1 8-inch double block for 1-inch rope
100 feet 1-inch Manilla rope
1 rope hook
2 jacks
1 brace; assortment of bits
1 tape or rule
1 broom
3 kerosene lanterns or gasoline lanterns
1 5 pound pick
1 tile spade

1 shovel, long handle
1 20-foot, length, 2-inch, suction hose with strainer
1 2-inch foot valve

terial for commencing the drilling operations. On the other hand, since this list is made up from a composite of the inventories of several different oil companies and one contracting company, it is unlikely that in any one case the entire list would be selected, for local conditions and personal judgment modify individual requirements.

The choice of the type of drill will depend largely upon the depth to be drilled, the cost of fuel, and character and availability of water. Cheap coal and an abundance of pure water make a steam drill desirable, but if coal laid down at the drill is expensive and if the water is scarce or of such a nature as to cause trouble in the boiler, a gas-driven drill is preferable. Another advantage of the gas drill lies in the time saved in moving. Drills of three different capacities are on the market for this type of work; one class is capable of drilling "N" holes up to 2,000 feet in depth; another, up to approximately 1,000 feet; while drills of the third class will drill this size hole efficiently up to 100 or 200 feet. Any drill can exceed its normal capacity under favorable conditions.

In entering the core-drilling field for the first time it would not be wise for a purchaser to stock up at the start with all of the items listed as accessory equipment (Table I, 4*b*), but to rely on local farmers for his teaming until he has organized his work to meet best his individual requirements.

COST OF EQUIPMENT

The cost of a diamond drill outfit for drilling holes 500 feet in depth, as listed in Table I, is, roughly, as follows:

1. Material to be purchased from diamond drill manu-manufacturer	$6,000 to	$ 7,000
2. Flush-joint casing (omitted)		
3. Carbon	2,200 to	4,500
4. (*a*) Casing and casing equipment	250 to	275
(*b*) Accessory equipment	150 to	1,750
(*c*) Small tools	160 to	200
Total	$8,760 to	$13,725

The figures above include the cost of 500 feet of "N" drill rods and 200 feet of 3-inch pipe for casing, but do not include any of the items listed in Section 2. Any variation in the amount of drill rods or of 3-inch casing will alter the estimate accordingly. The cost of the carbon will depend upon the number, size, and grade of stones selected. Two four-stone bits, averaging $2\frac{1}{2}$ carats to the stone, and worth $110 the carat, will cost $2,200. Two six-stone bits, averaging $2\frac{3}{4}$ carats, at $135 the carat, will cost $4,455. Four stones in a bit is common practice, but the use of six stones is preferable. In the long run it is probably poor economy to purchase any but the best grade of carbon. The cheaper grades crumble and break easily. A saving in the initial cost of the drill outfit can be made by omitting such items as truck and tractor.

The diamond drill has firmly established itself as an indispensable part of oil exploration equipment, whether used for checking up the obscure parts of structures that have been suggested by surface geology, following up indications furnished by geophysical measurements, or systematically blanketing a block of leases with drill holes in the hope of discovering any structure that may be present. The continually increasing use of the diamond drill for this specialized type of work will result in improvements in machinery, equipment, and operating technique, which in turn will produce greater drilling economy and thus permit a wider application of diamond drilling to the oil producer's problem of satisfying the demand for petroleum.

THE GEOLOGIC HISTORY OF THE PANUCO RIVER VALLEY AND ITS RELATION TO THE ORIGIN AND ACCUMULATION OF OIL IN MEXICO

EARL A. TRAGER[1]
Ponca City, Oklahoma

ABSTRACT

The paper describes the geological section as present in the northern producing fields of Mexico, outlines the regional geologic features, and discusses the relation between these features and the accumulation of oil in Mexico. The writer also discusses the probable source of the Mexican oil.

ACKNOWLEDGMENT

The area under discussion is the entire Panuco district or the northern oil fields of Mexico. The author wishes to present certain interpretations and a summary of the geologic history of this district, based on several years' investigations for the Marland Oil Company of Mexico. Previous to the work done by the writer an excellent surface study of the area was completed under the supervision of Mr. C. E. Hyde, now vice-president for the Marland Oil Company of Texas. The Velasco and Papagallos shales were subdivided by Dr. Joseph A. Cushman by the use of Foraminifera. Conferences were held with other workers on several occasions. Among those attending were Messrs. W. A. J. M. Van der Gracht, Joseph A. Cushman, R. T. Chamberlin, W. H. Hobbs, Geyer, Aurin, Clark, and Willis. The entire study was under the personal direction of Mr. Earl Oliver, former general manager, many of whose ideas are presented herewith. The work, ideas, and suggestions of all these men have been drawn upon in the preparation of this paper, and the author wishes to acknowledge gratefully, and express his appreciation for, the help which has thus been rendered.

INTRODUCTION

Oil production in Mexico is obtained from limestone beds and not from sand layers, as is most frequently the case in the United

[1] Chief of Geological section, Research Department, Marland Oil Company, formerly chief geologist, Marland Oil Company of Mexico, S. A. Presented at Annual Meeting of American Association of Petroleum Geologists, Wichita, March 28, 1925.

States. Structures, such as folds and block faults, are present, and commercial production is generally obtained from places where these folds or blocks have elevated the producing horizons to a relatively high position. However, in the Panuco district especially, it is necessary to have more than high structure to obtain oil in commercial quantities. The producing horizon being a limestone, it is necessary that this limestone be considerably broken or shattered in order to produce a reservoir for the oil. Another most important factor, which is frequently overlooked, is that this reservoir, once formed, must be favorably located with respect to a source for oil. The conclusions herewith presented are based upon observations which were made to determine these various factors and their relationship, and which may be summarized as follows:

1. The structures present in the Panuco district have a general north-south trend.

2. The production extended in an east-west belt rather than in a north-south direction.

3. Fracturing is necessary for accumulation.

4. There is probably a belt of fracturing extending subparallel to the trend of production.

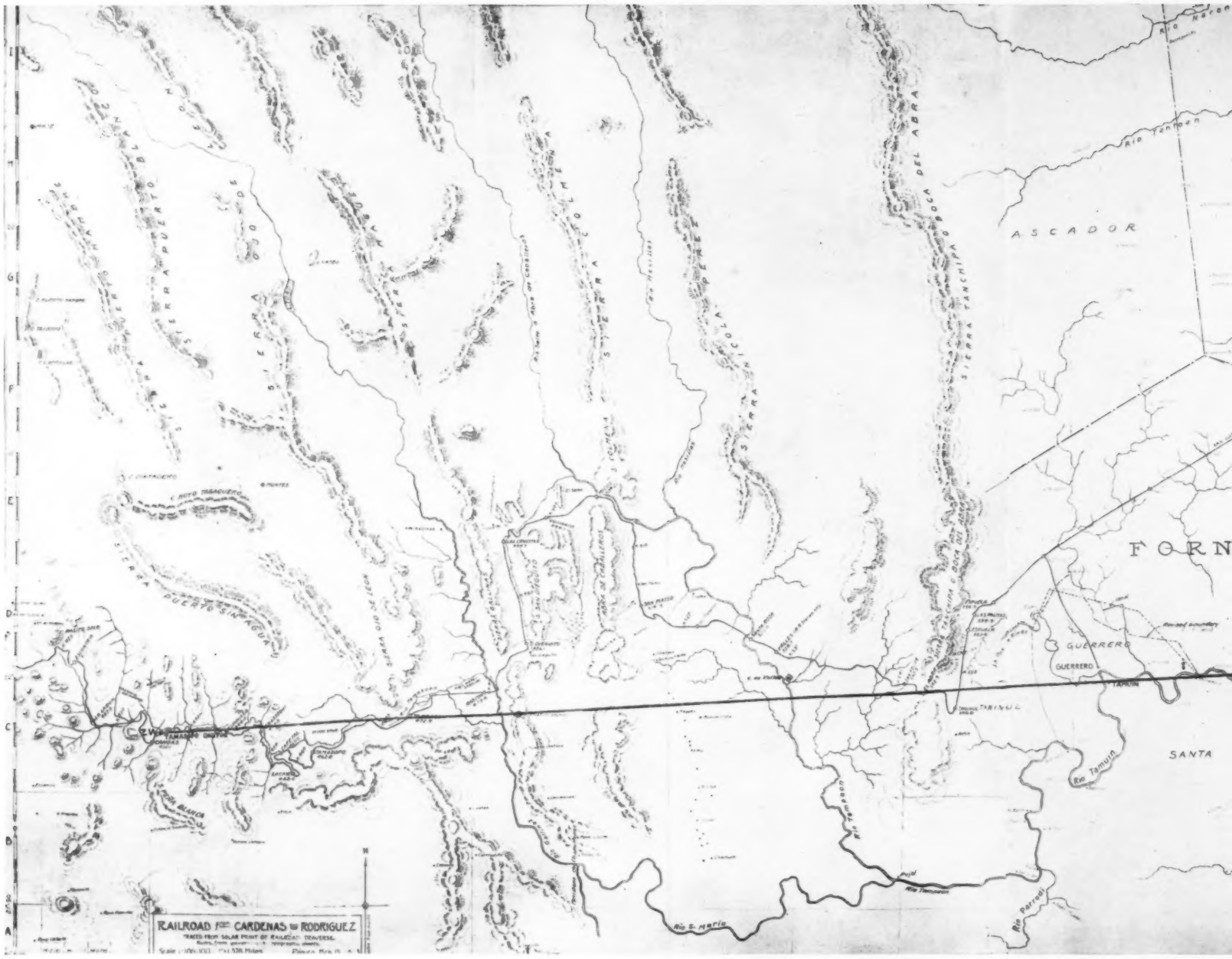
5. The oil probably originated in the shales above the producing horizons.

This discussion will apply particularly to an area, extending about 50 kilometers from north to south and about 110 kilometers from east to west, which is located west of Tampico and which includes the Panuco River area (Fig. 1 and Plate 23).

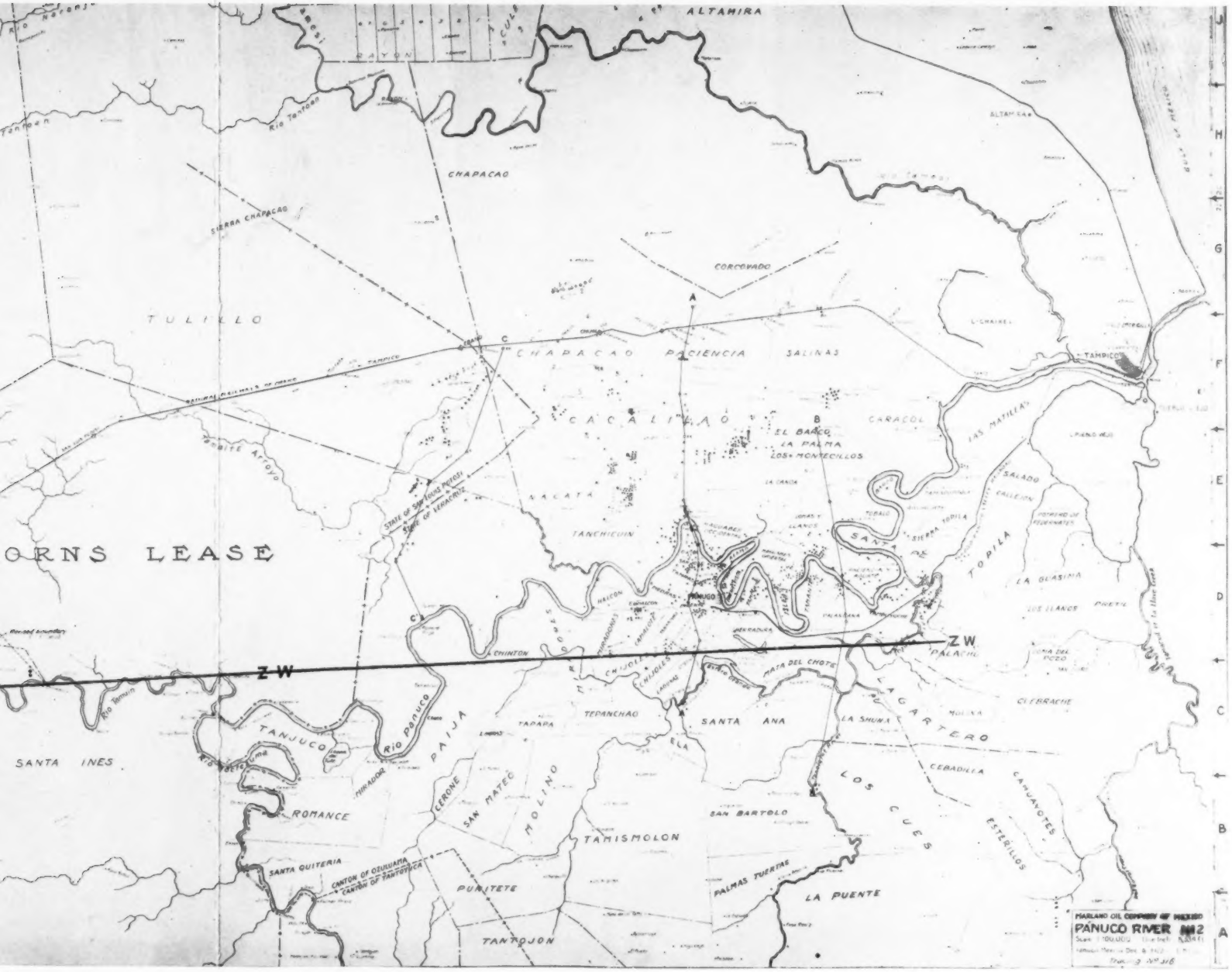
GEOGRAPHY

TOPOGRAPHY AND VEGETATION

The principal drainage within this area is southward to Panuco River and thence eastward to the Gulf of Mexico. The eastern half of the district is a low-lying swampy plain covered with grass, *chovenal* swamps, lagoons, and a few low hills, some of which are structural, but most of which are erosional remnants composed of gravel. The average elevation of the Panuco River Valley is 30 to 60 feet. In passing northward from the tract outlined, the elevation gradually increases to about 200 feet.



MAP SHOWING APPROXIMATE POSITION OF ZONE OF WEAKNESS, LOCATION OF



OCATION OF CROSS-SECTIONS A–A,' B–B,' C–C,' AND AREA OF PRODUCTION

The western half of the area, somewhat higher than the eastern, gradually rises to about 150 feet. Here there are several surface folds extending approximately north-south. The surface is comparatively open in places, but much of it is covered with mesquite, palm forests, or tropical jungles. There are very few roads and travel is most difficult, as it is necessary to cut a trail through the dense vegetation wherever one leaves the main roads. The western boundary of the

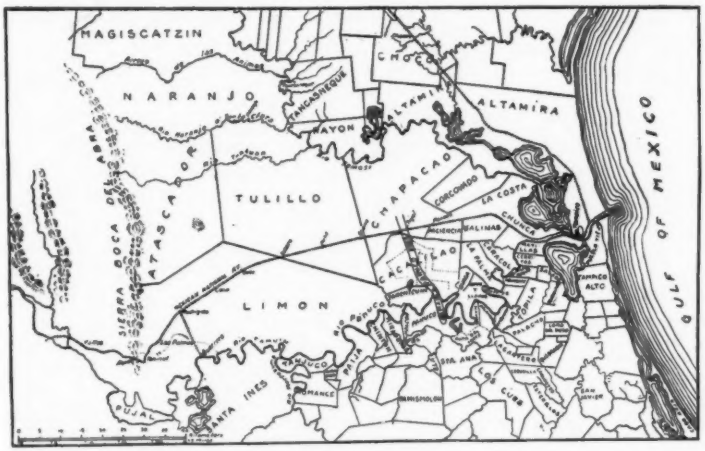


FIG. 1.—The Panuco River district of Mexico

district is formed by the Boca del Abra Mountains, the eastern face of which is a nearly vertical fault scarp. These mountains rise 600 to 800 feet above the plains.

WATER SUPPLY

The water of Panuco River is potable except in the vicinity of Tampico, where it becomes salty due to mixing with waters from the Gulf of Mexico. Moctezuma and Tamuin rivers, tributaries of the Panuco, also contain potable water. A rather large stream, the Rio Choy, whose origin is in a large cave called the Nacimento, is located several kilometers north of the Station Taninul, at the base of the Boca del Abra Mountains. A much smaller stream, supplied by small springs in the Boca del Abra Mountains, is located about 15 kilometers north of the Rio Choy. The Rio de Tantuan is a very small stream, except during the rainy season. The Rio Santa Clara, or Naranjo, is also small, but con-

tains a larger volume of water than the Tantuan. The Rio Tamesi is capable of supplying a very large quantity of water. All these streams contain a high percentage of lime in the vicinity of the mountains.

Throughout the remainder of the district water is obtained generally through the medium of a rain-barrel, from small arroyos during the rainy season, from lagoons, or, occasionally, it is shipped in. Much drinking water is transported long distances, in five-gallon cans or small kegs carried by burros. The water in most of the lagoons is yellow to dark-brown in color, and has a very decided taste of moss or decayed vegetation. Filtering, boiling, and the addition of tea does not remove this taste. When working in this district it is a wise precaution to carry drinking water at all times.

CLIMATE

The climate in this part of Mexico is classed as subtropical, but is rated as tropical by insurance companies because of the humid atmosphere, general absence of sanitary measures, and the unfavorable conditions during the rainy season. There are two seasons, one dry and the other rainy, but the division between them is not sharply defined.

January belongs to the dry season, but rains continue at intervals until well into February. "Northers," so famous throughout the South, marked by a drop in temperature to 50 degrees or less, and possibly accompanied by showers, occur in January. They last from two to five days. Between them the temperature rises to as much as 80 degrees. February is more definitely in the dry season, and from this time until May the temperature rapidly increases. May is considered the peak of the dry season, but occasionally higher temperatures are reached in June than in May. The average temperature during the hot part of the dry season is from 100° to 106° in the shade. A thermometer placed directly in the sun during the hot part of the day will register 135° to 140°.

The rains set in during June or July. At first there are occasional showers, the chief result of which is a slight lowering of the temperature. Hot, sultry weather, with occasional showers, continues until August, during which month it is usually dry. Early in September the severe rains of the wet season begin and continue with little interruption for about a month. Panuco River frequently rises 5 to 10 feet in a 24-hour period. Once or twice each rainy season it will rise about 25 feet during a 30- to 48-hour period. After September or the middle of October the rains gradually subside, becoming less frequent in occurrence and diminishing considerably in the amount of precipitation.

Most of the roads are impassable for automobiles during September and October, and many of them, during November. In fact, all the roads do not become generally passable until late in January.

STRATIGRAPHY

A knowledge of the generalized section is needful in following the subsequent discussions. The best section for reference purposes is

that on the crest of the Panuco high, to which may be added the material which has been eroded. A graphic representation of this section is given in Figure 2. The formations will be described in the order in which they were deposited.

JURASSIC

Recently several wells have been drilled into the Jurassic, but the detailed information concerning this discovery is not available for publication at this time. The Jurassic in this district is composed of a hard, white, finely crystalline, sandy limestone containing a few fossils.

CRETACEOUS

Tamaulipas or Tamasopo.—The deepest horizon to which drilling for oil is generally prosecuted in the Panuco district is about 300 feet below the top of the so-called "Tamasopo limestone." This limestone, which is encountered in wells within the Panuco district, is unlike that which crops out in the Tamasopo Canyon, and also unlike the producing limestone of the South fields of Mexico, which also is called Tamasopo. The limestone from the South fields is most probably equivalent to that which crops out at El Abra, immediately west of the area under discussion. Recent field studies have indicated that the limestone encountered in the Panuco district is similar to that which crops out in the Tamaulipas range, and for this reason many of the Tampico geologists have united in an effort to have this limestone termed Tamaulipas.

Certain of the Tampico geologists maintain that since the term "Tamasopo" is a misnomer it should be striken from the literature. This is rather a radical procedure, especially since the term is so well fixed in the literature. Hundreds of reports dealing with Mexico contain this term and have used it to designate the Lower Cretaceous producing horizon. If the present idea of the correlation of these two horizons is correct, then they are two adjacent beds separated by an unconformity. To drop the term completely would only add to any confusion which may now exist.

The author proposes that the name Tamasopo series be applied to that part of the Lower Cretaceous section which includes the two important producing horizons. This series may be divided into two parts: (1) The upper part, which is the Lower Cretaceous producing

GENERALIZED SECTION OF THE MEXICAN CRETACEOUS
AS PRESENT IN THE PANUCO DISTRICT.

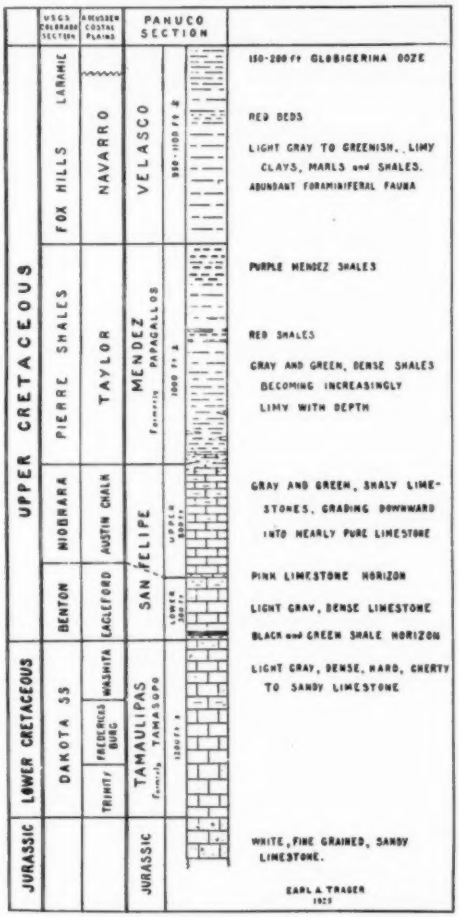


FIG. 2

horizon in the Northern district, is named the Tamaulipas. Tamaulipas has been proposed because of its typical exposures in the state of Tamaulipas. (2) The lower part, which is the producing horizon in the South fields and which is typically exposed at El Abra, for which the term "El Abra" is proposed. Such a classification as this will greatly facilitate those less familiar with the circumstances in correlating the literature of the past with that of the future.

The exact relationship between the producing horizon of the South fields and that of the Panuco field, both of which have been termed Tamasopo, is not known. The top of the Tamasopo of the South fields is very badly eroded and it is thought that the Tamaulipas of the Panuco district unconformably overlies the Tamasopo of the South fields.

In outcrop the Tamaulipas is a thin-bedded to massive, white to gray, finely crystalline limestone which has been accorded thicknesses of more than 3,000 feet. This limestone underlies a large part of Mexico and is easily distinguished by its physical properties combined with its abundant fauna. It is in part, if not entirely, Lower Cretaceous in age.

Characteristics of the Tamaulipas limestone as determined from drill cuttings.—The uppermost Tamaulipas is a white, dense, very finely crystalline, cherty limestone. It ranges in thickness from 10 to 60 feet. The chert is light-colored—white, opaque, and pearly; it is present in the form of bands, pockets, or nodules. No evidence of great amount of erosion has as yet been found, but there is most probably a disconformity at the top of the Tamaulipas. This chalky white bed is thickest above the high parts of the fold and decreases in thickness on its limbs.

This white limestone and the upper 25 feet of the gray limestone underlying it are among the most important producing horizons in Mexico. Based on the number of wells producing from this horizon, it is probably second in importance in the Panuco district.

Many large fragments, which have been blown out of wells or recovered in drilling, have clearly indicated that the reservoir space has been formed by the fracturing of this limestone. Fracturing in massive Tamasopo (El Abra), as seen in outcrop, is illustrated in Figure 3.

Below the white limestone is gray to taupe, fine-grained, cherty limestone which is comparatively thin-bedded. The chert is dark, usually smoky or black, though some of it is lighter colored. Some of the limestone beds are slightly sandy in places. Frequently there are thin laminae or partings of very dark gray or black shale. The amount of shale varies considerably in the different wells, but at no place does it represent a large percentage of the total mass.

FIG. 3.—Fracturing in massive Tamasopo (El Abra) limestone as seen in outcrop.

Three hundred foot break.—About 200 to 300 feet below the top of the Tamaulipas is a second series of white limestone beds alternating with black limestone and shale. The thickness of this horizon is less than 100 feet. The limestone contains much black chert. Cuttings from this zone appear very dark because of the black shale but the amount of black material is generally less than 25 per cent. This horizon is frequently referred to as the 300-foot break.

A few producing wells have been obtained from this horizon and immediately below it. The zone ranks fourth in importance in Mexico.

Below the dark-colored beds is white, fine-grained, heavily-bedded limestone which contains traces of chert. Most of this limestone is quite uniform in appearance. There is a third black lime-

stone series, containing some black shale 20 to 40 feet thick, whose usual position in this section is 500 to 600 feet below the top of the Tamaulipas. About 1,000 to 1,500 feet below the top of the Tamaulipas the limestone becomes slightly areanaceous and contains much pyrite that oxidizes rapidly and imparts a dark-brown color to the sample. The character of the limestone, to the total depth to which it has been penetrated, does not change appreciably.

Foraminifera are exceedingly rare in the Tamaulipas limestone. If the determination of Jurassic is correct, then the Tamaulipas limestone is considerably less than 3,000 to 5,000 feet thick within the Panuco district, as has been previously inferred from outcrop data.

San Felipe (San Juan) formation.—The San Felipe, or San Juan, beds, as they were formerly called, occur immediately above the Tamaulipas limestone. The range in thickness of the San Felipe series is 700 to 1,000 feet. The thickness above the various highs in the central part of the Panuco field averages 700 to 800 feet. Lithologically this series is readily divisible into two parts. The Upper San Felipe can be divided into two parts, which, however, are not greatly different. The Lower San Felipe is readily divisible into three parts, the lowermost of which is negligible over high structures.

The Upper San Felipe.—The Upper San Felipe, uniformly about 500 feet thick, consists of green, greenish-gray and gray, limy shale, lenticular limestone, and shaly limestone, all of which characteristically have a mottled appearance. The uppermost San Felipe grades upward into the Mendez (Papagallos) shale which overlies it, the demarcation between these two formations being difficult to determine. The point at which the first definite limestone "shells" are encountered is arbitrarily considered to be the top of the San Felipe. The contact between the San Felipe and Mendez is more easily determined in outcrop than it is from well cuttings. Weathering along the outcrop disintegrates the shale, making it more easily distinguishable from the lime "shells" than is the case with unweathered material. Figure 4 shows an exposure very near, if not at, the contact of the San Felipe and Mendez at the type locality of San Felipe. The lime "shells" can be distinguished by their more angular outline. This uppermost part of the San Felipe section is dark,

greenish-gray, generally darker than the overlying shale. It is composed of limy shale alternating with thin limestone "shells." Going downward in the section the amount of limestone increases until a point is reached, about 200 or 250 feet below the top, below which the formation is predominantly limestone.

FIG. 4.—Contact of Mendez (Papagallos) and San Felipe limestone at type locality of San Felipe.

There are several lateral gradations in the San Felipe worthy of note. Westward from the Panuco high this formation is uniform in character over large areas. Northward it thickens, while eastward it becomes more shaly and sandy.

Foraminifera are of little value in determining the contact between the Mendez and San Felipe, several species being present in both, though generally the number of individuals is very much smaller in the San Felipe and some of the species are also dwarfed. There is one species which is characteristic of the San Felipe, but it is rare and consequently difficult to find. In addition, the limy, and consequently harder, character of the San Felipe makes it very difficult successfully to wash out the micro-fossils from this formation.

The lower part of the Upper San Felipe is characteristically a hard, dense, shaly limestone, greenish in color and mottled in appearance. Plate 24, Figure 1, illustrates typical Upper San Felipe

mottling. The lower 50 to 75 feet of this series is light-green in many places and has associated with it numerous traces of pink limestone and calcite. On the highest part of the fold there appears to be a single bed of pink limestone about 300 feet above the Tamaulipas (Tamasopo). On the flanks of the fold there are several occurrences of pink limestone scattered over 50 to 100 feet of the section. At the base of the pink limestone is some dark, purplish, shaly material, and most frequently the matrix is a lighter green at this point. This is the most consistent of the pink limestone occurrences, and consequently the most valuable for correlation purposes. The base of the green limestone, with pink inclusions, is considered to be the base of the Upper San Felipe.

The Upper San Felipe was undoubtedly deposited in a comparatively shallow, oscillating sea. Examination of several diamond drill cores has shown five or six definite partings which indicate slightly eroded surfaces, possibly ripple- or wave-marked, which are separated by very thin shale or bentonitic laminae. Two cases were observed which very definitely indicated an oscillating condition in which, between two layers of San Felipe limestone, there was deposited about an inch of nearly white, fine-grained, sandy limestone containing traces of volcanic ash and mica, together with pieces of fragmental limestone as large as one-half inch in diameter. The nearly white band of material in Plate 24, Figure 5, is one of these layers.

No commercial oil production of importance has been obtained from the Upper San Felipe in the Panuco district. Fractures in basal Upper San Felipe beds containing oil are shown in Plate 24, Figure 3. Occasionally a well begins to produce in the lowermost part of the pink lime horizon. Most operators pay little attention to a drilling well until it reaches the pink limestone horizon, after which point it is carefully watched, for production may be encountered at any point within the next 400 feet of section immediately below this horizon. In the Ebano district, including Chijol, Dicha, La Pez, Laguna, and Margaritas, many commercial oil wells have been obtained in the Upper San Felipe. For the area under consideration this horizon ranks third in order as a possible source for petroleum.

Lower San Felipe.—On the higher parts of the fold the contact between the Upper and the Lower San Felipe is quite easily de-

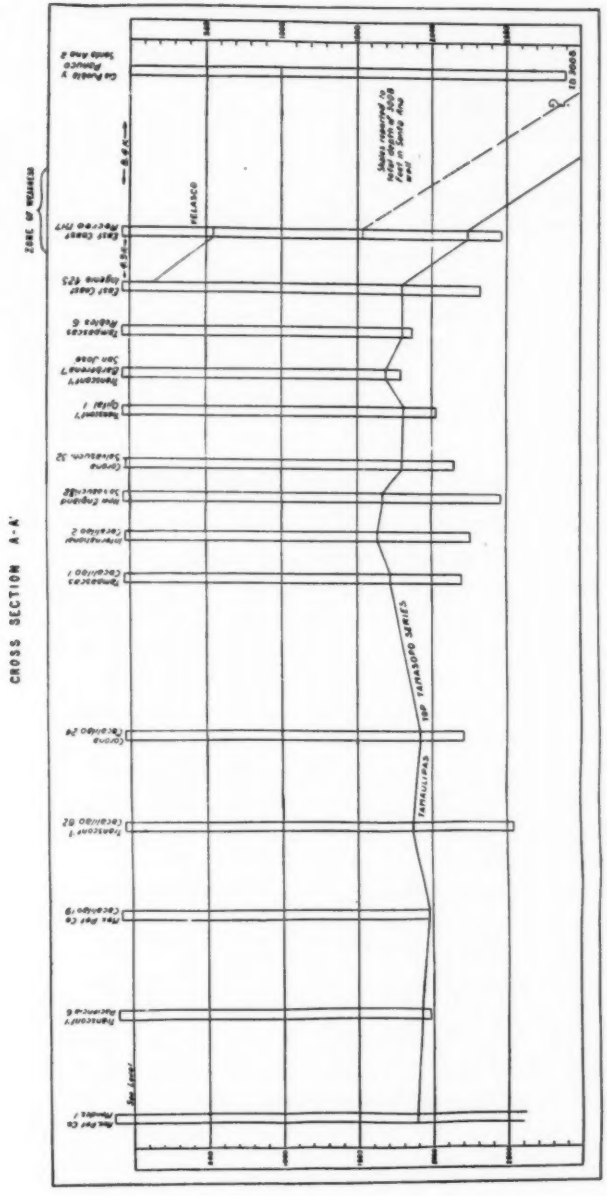


FIG. 5.—Section A-A', showing depth to Tamaulipas along crest of the "Panuco high"

termined, the base of the pink limestone being considered the dividing line. The limestone below this point is more crystalline and more sandy in texture. In addition to the difference in texture there is a difference in color. The Upper San Felipe series is predominantly green, while the Lower San Felipe beds are gray to nearly white, with bands of dark gray to nearly black shale or limestone at certain horizons.

The Lower San Felipe is readily divisible into three parts in those areas which contain the complete section. The uppermost division, termed by some the "Blue-gray series," consists of transition beds; these are composed of gray, shaly limestones which contain lenses of very dark gray to nearly black, dense limy shale, or shaly limestone. The texture of this part of the Lower San Felipe is more similar to that of the Upper San Felipe than is that of the remainder of the section. The percentage of dark material varies considerably, but it is generally great enough to give all these samples a dark appearance. This part of the section is not as well represented on the crests as on the flanks of the folds. Lateral changes indicate minor variations in deposition, probably due to comparatively shallow, oscillating waters. The thickness of these beds ranges from 50 to 200 feet.

The middle member termed "Panuco gray," is by far the most important commercially. It is composed of a very light-gray, hard, dense, slightly sandy, micro-crystalline limestone which is similar in appearance and texture throughout its entire thickness of about 100 to 200 feet. Fracturing is very common in this limestone, and can frequently be seen in large hand specimens obtained by rotary coring, diamond drill, or which have been blown out by gas. Plate 24, Figure 2, illustrates the texture of this limestone and shows also a band of dark green bentonite. The large black spots are oil stains. Crevices as large as one-half inch or more in diameter, whose walls contain a coating of small calcite crystals, have been observed in hand specimens. Plate 24, Figure 4, taken vertically from a section of a diamond drill core of this limestone, shows a crevice containing a small amount of oil which stained the limestone on either side of it. Frequently movement along fractures or bedding planes produces slickensided surfaces in this hard limestone. A slickensided

surface observed in a diamond drill section is illustrated in Plate 25, Figure 2. This division of the San Felipe ranks first in order of importance as an oil-producing horizon in the Panuco or northern district of Mexico.

The third and lowest division of the Lower San Felipe ranges in thickness from 5 to 300 feet. Over the Panuco highs there is from 5 to 10 feet of material, most of which is black shale and black crystalline limestone, with a thin bed of dark-green bentonite at the base. Very small fragments of this green material are frequently included in the black limestone. At the western edge of Cacaliao this black series is 60 or 70 feet thick, and this thickness remains quite uniform over the eastern end of the Limon. On the western end of the Limon, and northward to Naranjo, thicknesses of 300 or 400 feet have been observed. Where the thicknesses are greatest the material is predominantly very hard, black, cherty, crystalline limestone, whose matrix is composed of angular crystals. Black, limy shale laminae are also present. The entire thickness of this limestone is practically lacking in fossils, with the exception of a thin bed at the top and another at the base. The black shale and limestone series is considered equivalent to the Eagle Ford of Texas.

East of the Panuco high there is reported about 50 feet of dark brown, sandy limestone, containing chert, which is probably equivalent in age to these beds.

The writer is of the opinion that these beds represent a period of erosion. Until recently there has been very little evidence concerning this part of the section other than the change in thickness of these beds. A diamond drill core, recently taken by the International Petroleum Company through these beds indicates dips ranging from 35° to 65°, the steeper dips being toward the base. Plate 25, Figures 1 and 3 illustrate two parts of this core, in both of which the bedding is clearly defined. The first shows small fractures at right angles to the bedding, which are sealed with calcite. Sections of the same core taken from above these black beds indicate dips of less than 10°.

It is probable that there was movement in the region of the Boca del Abra Mountains during the time that these beds were being deposited. This movement followed the period of vulcanism, during which the ash beds were deposited, that later formed the deposit of

bentonite which is present at the top of the Tamaulipas (Tamasopo). It was probably in the form of a gradual settling in the west, as indicated by the greater thickness in that direction. Very few wells have been drilled in this western district, and for this reason there is not much evidence upon which to base conclusions.

So far as is known the "Panuco gray" lies conformably on the basal black limestone. If this is true there must have been an emergence, and period of erosion, at the close of the middle Lower San Felipe. Most, and sometimes all, of the "Panuco gray" is absent in the Boca del Abra region. Those remnants which have been observed have the same texture as that in areas where the total thickness is present.

The type of material composing the transition zone above the "Panuco gray" indicates deposition in more shallow waters than those which were present during the "Panuco gray" period. This fact also indicates a minor oscillation, at least, about this same time.

In places where the black limestone series attains considerable thickness the green bentonite[1] bed, characteristic of its base, is not well defined. Small fragments of green bentonitic material, however, are contained in the lowermost part of the black limestone. This bentonite extends from northern to southern Mexico, and, as its base is considered the base of the San Felipe, it is for this reason of considerable importance.

Mendez (Papagallos) formations.[2]—At the close of the Upper San Felipe there was no emergence of the land, but rather a sinking of the basin increasing the area of inundation, during which the sea spread to the north, east, and west. The San Felipe series is composed predominantly of lime, while the basal Mendez is characterized by limy shale alternating with thin limestone "shells," which grade into limy shale whose lime content decreases progressively toward the top.

The Mendez formation, as present in the central part of the

[1] W. M. Bramlette, "Bentonite in the Upper Cretaceous of Louisiana," *Bulletin American Association Petroleum Geologists*, Vol. 8, No. 3, (May–June, 1924), pp. 342–44.

[2] At a recent meeting of Tampico geologists it was decided to supplant the term "Papagallos" by "Mendez."

Panuco district, is composed of 1,000 feet of greenish or grayish limy shales which are quite uniform in character with the exception of the fact that the lower several hundred feet are more calcareous contain a few lime "shells," and are generally much harder. With the exception of a few red beds which occur in the upper 300 feet, and a second series of red beds in the lower 250 feet or less of the section, the Mendez shale cannot be differentiated lithologically into subdivisions.

The shale contains an abundant foraminiferal fauna in its upper part, and in its lower part, a fauna which contains fewer individuals and fewer species. A very distinctive fauna in the upper 300 feet of the Mendez contains a number of species decidedly different from those below this horizon. The Mendez formation is probably equivalent to the Taylor marl of Texas.

The seas, in which the Mendez shale was deposited, apparently became deeper during the middle part of the period, as evidenced by the types of Foraminifera present. The average thickness of the Mendez is rather uniform throughout most of the district north of Panuco River; however, south of a zone of weakness, to be described more in detail later, which is more or less tangent to the south bends of Panuco River (approximate position shown in Plate 23), it rapidly increases in thickness. Evidently considerable settling took place south of this zone. No evidence has been observed of a major oscillation in which the formations either north or south of the zone were exposed to much erosion. Very probably a large part of this sinking took place during Middle Mendez times.

There is evidence that some structural movement over the Panuco high may have taken place toward the close of the deposition of the Mendez. Generally there is but a single red bed over the major part of the Panuco high, while on the flanks several such red beds appear; also it has been observed that many of the Foraminifera, which are present in these red beds of the Upper Mendez, have been exposed to weathering and are frequently coated with iron oxide. The Foraminifera both above and below these red horizons do not appear to be weathered in like manner, notably in cases where the red horizons are encountered as much as 900 feet below the surface.

The top of the Mendez is not easily distinguishable in the field,

for it is apparently overlain conformably by Velasco. Careful observation, however, will allow the placing of this contact within a few hundred feet, possibly. The Mendez frequently weathers into various shades of green and purple, containing in its upper part red beds which have a purplish hue. These red beds are composed of very limy shale and are frequently harder than the material above or below them.

The Velasco, overlying the Mendez, might be described in outcrop as a limy clay rather than a limy shale, and the red beds which it contains have less of a purplish cast. In examining the Velasco under a hand lens the impression is obtained that these beds are more porous than the Mendez. No evidence of any considerable unconformity has ever been found. The faunal break, however, between the two formations is a very decided one.

The Mendez shale is of little importance as a possible reservoir for petroleum. A few wells have produced small quantities of oil from the basal Mendez in the Ebano district.

Velasco Formation.—The Velasco formation is the youngest Cretaceous known to be present in the Panuco district. It is composed of at least 950 feet, and possibly as much as 1,100 feet of limy clay, shale, and marl. This series apparently lies conformably on the Mendez; however, there is evidence which indicates that probably the waters in which the uppermost Mendez and basal Velasco were deposited became very shallow. It is quite probable that there were numerous minor oscillations, some of which may have exposed parts of the Velasco to erosion for short periods. The red beds in the uppermost Mendez and basal portion of the Velasco suggest that some such condition might have existed, as also does the presence, near the contact, of Foraminifera which have been slightly weathered or oxidized, and also the presence of species which belong to relatively shallow waters. The contact between the Mendez and Velasco is very difficult to place within narrow limits by the use of lithology; however, the Foraminifera in the two formations are so very distinctive that this contact can easily be placed within 10 feet in a set of well samples. Early during the Velasco period the sea became very deep, for the fauna is characteristically a deep-water fauna.

The Velasco series is very difficult to separate on a lithologic

basis into small divisions. It is composed predominantly of gray, blue, and occasionally greenish, beds of limy clay. In some localities red beds are present near the base and upward as high as 250 feet in the section. The basal part of the Velasco is similar in appearance to the Mendez, while the upper part is more easily distinguishable lithologically.

The foraminiferal fauna in the Velasco is an exceedingly large one, one-fourth of certain beds consisting of foraminiferal remains. Many new species appear at various horizons, and a careful study of these species, and their ranges, makes it possible to correlate various horizons in the Velasco within rather narrow limits. This is probably the only method applicable for detailed structural work. The foraminiferal fauna is equivalent to the Navarro of Texas.

Near the top of the Velasco there are several rather abrupt faunal changes, but no evidence of an unconformity has been observed. The lower 900 to 950 feet of the Velasco is a closely related series, as interpreted by the foraminiferal faunas. Above this there are 150 to 200 feet of material which may or may not belong to this formation. This upper material is composed mainly of soft, limy clay and marl, generally gray. It contains a fauna of Foraminifera very closely associated to the Velasco, and one which indicates deposition in waters deeper than typical Velasco. This fauna is of the type contained in deep-sea *Globigerina* oozes. The general appearance of this fauna is Cretaceous, although it has also an Eocene aspect. However, no characteristic Eocene type species have as yet been found in these beds. These facts suggest the possibility of a period of minor oscillation preceding the deposition of this uppermost marly material.

The Velasco grades upward into the Eocene without any marked unconformity, but probably through a transitional stage. The overlying Eocene was deposited in comparatively shallow, oscillating waters. Many large and ornate forms of Foraminifera are present in the basal Eocene, none of which have been observed in the Velasco. The contact between the Velasco and the basal Eocene (probably Chicontepec) is considered the division line between the Cretaceous and the Tertiary for this district.

STRUCTURE

The territory considered in this paper is a large block which has been faulted down in relation to the Boca del Abra Mountains on the west. The fault scarp which defines the eastern face of these mountains rises 600 to 800 feet above the plains on the east. The amount of vertical movement along this fault plane was probably at least 5,000 feet. The trend of the crest of the Boca del Abra Mountains averages 10° N. to 15° W. In the region between these mountains and the Gulf of Mexico there are a number of small anticlines, some of which are visible at the surface, all with axes generally parallel to the Boca del Abra Mountains.

The most intense of these folds is that which is commonly known as the main Panuco high. This high extends from south of the town of Panuco, and continues in a generally north-northwest direction through Salvasuchi, Cacalialao, and Chijol. There are several distinct folds along this trend. The northern extension of the high is composed of minor folds accompanied by minor faulting. The southern extremity of the Panuco high has somewhat the nature of a block fault, with a scissors type of movement on each side of the block. The eastern and western sides of this high at its southern extremity are probably bounded by faults, the vertical displacement increasing southward until cut off by a belt of east-west faulting.

To the east of the southern extremity of the Panuco high is a low terrace which is about 7 kilometers wide by 10 kilometers long. The depth to the Tamaulipas throughout this entire block is rather constant. Minor folds are present, the long axes of which trend in a more or less north-south direction. East of this block folding becomes more pronounced.

North of the block just described, and east of the Panuco high, are several small folds, and other larger ones, whose linear extent is subparallel to the Panuco high.

West of the main Panuco high the formations dip into a rather deep syncline. They again emerge in a regional high which passes through the Ebano field. Westward from Ebano to the Boca del Abra Mountains there are a number of folds which are subparallel to the mountains. The depth to the Tamaulipas in the western half

of this area is considerably less than between Ebano and the western part of Cacalilao.

Near the southern boundary of the region under discussion there is an east-west zone of weakness, which is most probably accompanied by faulting of the step variety, and which extends, as a narrow belt from the southern limits of the Topila fields on the east, westward into Tamasopo Canyon. The approximate position of this belt is shown on Plate 23 by the line *zw*. This is a very important structural feature, and even though we do not consider this belt to have extended in a straight line, as shown, this is what might be termed the mean position of a belt extending approximately from east to west, north of which the geologic features are considerably different from those south of it. There are a great many factors which give evidence of the presence of this zone of weakness.

Numerous folds, whose crests have extended considerable distances from the north, become broken or isolated structures as they approach this zone of weakness. For distances as great as 50 kilometers north of the zone, the depth to the Tamaulipas along the crests of some of these folds varies less than 200 feet. The depth to the Tamaulipas along the crest of the Panuco high is shown in Figure 5, Section A–A′. Immediately south of the zone the crests plunge very rapidly or disappear entirely. From wells which have been drilled on either side of the zone differences in depth to the Tamaulipas of more than 1,200 feet have been observed within a distance of 3 kilometers. The presence of this zone can be proved by the information obtained from deep wells which have been drilled, all the way from the Topila field on the east, westward to a point at least 15 kilometers west of the Panuco field. Figure 6, cross-section B–B′, illustrates this condition in the Topila district. Figure 7, cross-section C–C′, shows the same tendency west of Panuco.

There is surface evidence to indicate that it continues for a great distance beyond this point. North of this zone, on the Hacienda Limon, the surface is covered with Mendez and Velasco shales. Immediately to the south, on the opposite side of this zone and east of Moctezuma River, the surface exposures are Eocene, with occasional Oligocene outliers. This again indicates considerable adjustment on opposite sides of the zone.

The crest of the Boca del Abra Mountains remains at a comparatively uniform height for a distance of more than 50 kilometers north of the point at which this zone crosses the mountain range. South of the zone, the crest begins to plunge rapidly, and disappears

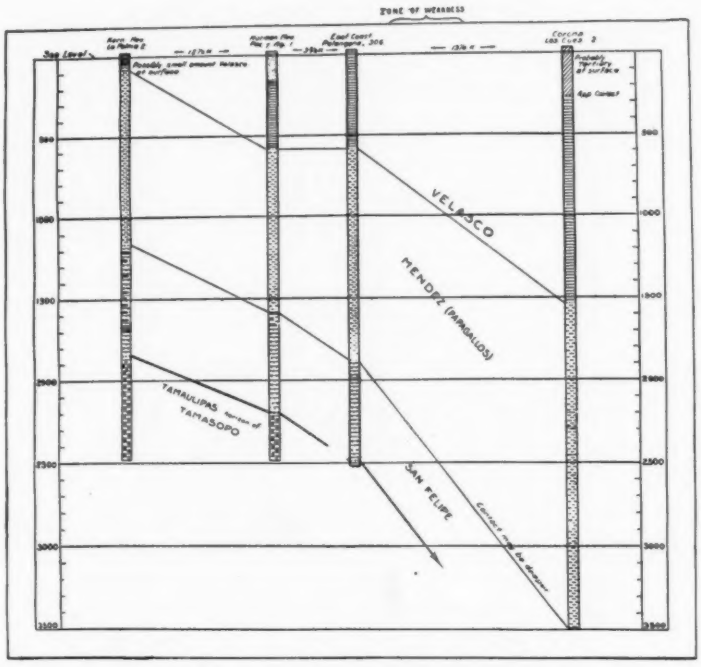


FIG. 6.—Cross-sections B–B′, generalized for Topila area

completely within a distance of 11 kilometers. Another physical feature of the Boca del Abra Mountains which lends evidence to the fact that the existence of this zone of weakness extends across it is the change in the direction of the fault trace and crest of the mountains. North of the zone its direction is about N. 12° W., while southward, instead of continuing in this direction, it turns slightly and is about S. 8° or 10° W. At Taninul there is a very deep gorge through the Boca del Abra Mountains, but apparently there is no

considerable vertical displacement between the north and south sides of this cut.

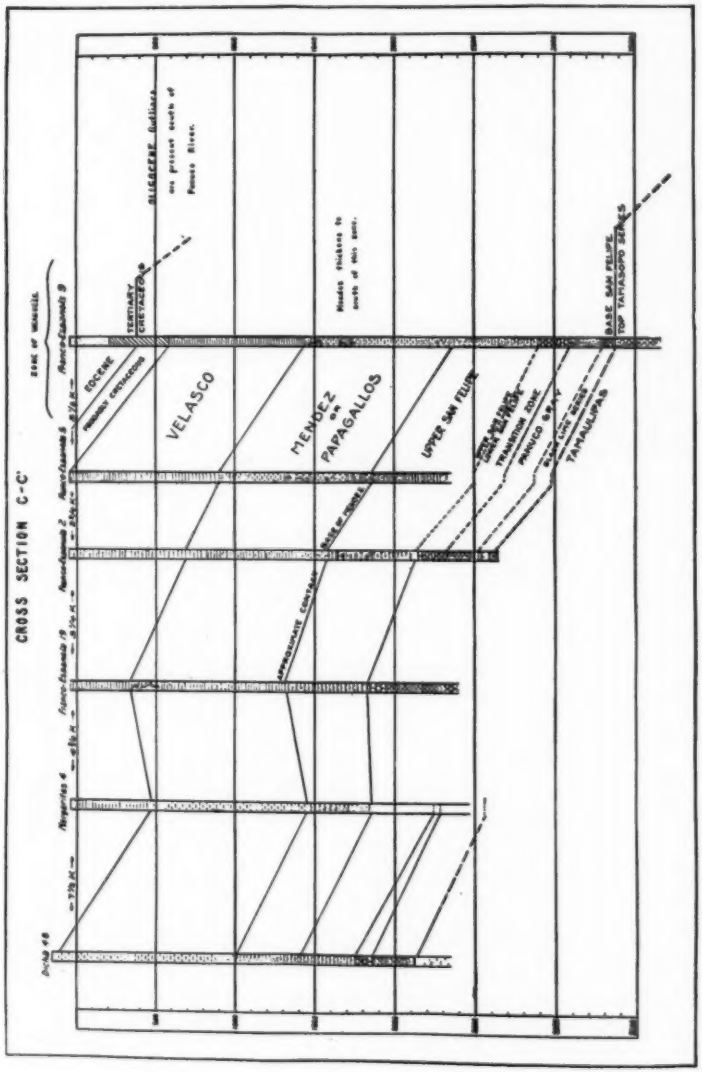


FIG. 7.—Cross-sections C–C', region west of Panuco

The projection of this line can be extended into Tamasopo Canyon. There are a number of mountain ranges between the Boca del Abra Mountains and the Tamasopo Canyon, all of which extend in a general north-south direction. A party of geologists was taken to the top of a high hill which is located nearly 3 kilometers southeast of the town of Rascon in the Sierra San Dieguito. From this point it was possible to look directly up into the Tamasopo Canyon to the west, and eastward toward Taninul. It was a noteworthy feature that the crests of the ranges present in this area all are broken, or contain considerable gaps, in the line of this projection, with one possible exception. This feature of the ranges is shown on Plate 23. The topography was taken from government maps, to which minor corrections were applied from the information obtained on an accurate railroad survey which was supplied us, the features involved in these corrections being also checked by field observation. Igneous dikes and flows are present at several points along the western extension of the projection. Surface evidence also tends to indicate that some adjustment has taken place along this zone or belt.

Early in the history of the Panuco field attempts were made to find extensions of the folds to the south, but, beyond a certain point, it was found that the depth to the Tamaulipas became exceedingly great. Due to the fact that the formations, from the surface down to the point at which the wells were abandoned, were practically all shale, certain of the geologic features were not discovered until recently. By the use of Foraminifera the shales can be differentiated and more definite information concerning the geologic features can be obtained. It has been learned that the Mendez rapidly increases in thickness south of this zone. Its normal thickness, of about 1,000 feet, has increased to about twice this amount within some 10 to 20 kilometers. Thicknesses as great as 3,000 feet have been observed farther south. The settling apparently took place gradually, throughout most of Mendez times, the greatest amount of displacement having taken place within, or adjacent to, the zone of weakness. This increase in thickness to the south has been observed to extend from the eastern end of the producing fields to the Boca del Abra Mountains on the west.

RELATION BETWEEN STRUCTURE AND COMMERCIAL PRODUCTION OF PETROLEUM

In Mexico, as elsewhere, it is generally true that the better producing territory is that in which the producing horizon has a relatively high elevation. High elevations, however, do not indicate the relative probability of commercial production in Mexico with the same degree of certainty as in districts where production is obtained from sand. In addition to having high structure, it is necessary to have a reservoir space. Such spaces are formed by shattering or fracturing the limestone, and consequently it is necessary that the high structure be in an area which contains fracturing. From such data, as are now available, it is indicated that minor faulting, alone, will not shatter the San Felipe and Tamaulipas limestones sufficiently to produce large reservoir spaces. Folding of a limestone will undoubtedly produce fracturing, but a study of the folds which exist in the northern part of the Panuco district indicates that minor folding alone is not sufficient to create a major reservoir.

Many of the structural highs in this area can be traced 40 or more kilometers northward. Structurally, the northern extensions of these highs are about 200 feet higher than the southern extensions, which are located in the Panuco district proper. By applying the usual criterion these northern extensions would be considered more favorable for petroleum production than the southern. Development, however, has proved that such is not the case. By consulting Plate 23 it will be seen that the general trend of the producing pools is east to west, rather than north to south, a trend contrary to the usual condition. It will also be noted that the important producing fields are located north of this zone of weakness, which is the high side. These pools extend northward as far as 25 kilometers from the zone of weakness, which, however, is less than one-half of the length of the structural trends. The most important of the producing pools are located within a much narrower belt north of the zone of weakness. More than one-half of all the oil produced from the entire northern district has been obtained from the belt immediately north of the zone of weakness, which belt represents not more than the southern one-fourth of the entire producing area.

The fracturing which was produced by adjustment along this

zone of weakness, especially that connected with the settling to the south, has probably been one of the important factors in centralizing production along a line which cuts across the southern extremities of many of these structures. Readjustment has undoubtedly produced more fracturing immediately north of the zone of weakness than is present farther north, and is accordingly largely responsible for the greater accumulation immediately north of it.

Another factor which indicates more intensive fracturing, and consequently greater reservoir space, adjacent to this zone is the fact that most of the old pools which were located north of the zone of fracturing were decidedly longer-lived than the more recent pools which have been located a considerable distance to the north.

Settling and readjustment such as that hypothecated along the zone of weakness will produce fractures approximately at right angles to this direction, in addition to parallel fracturing. These fractures will have the greatest amount of displacement adjacent to this zone, and will decrease in intensity in both directions from it.

The fracturing of the limestone in the Panuco district is undoubtedly intensive and dendritic in type. The breaks are not simple plane slips, but are very irregular in outline and extend by means of tortuous courses, most of which are intimately related, at least in the lowermost horizons. Over 402,000,000 barrels of oil have been produced from the northern district of Mexico. To store this amount of oil in a non-porous limestone would necessitate considerable fracturing.

During the early history of the field, when the depth to salt water was considerably below the producing horizon, operators were of the opinion that the fractures were not generally connected. It was thought that there might have been a number of fractured areas, each very small in areal extent and isolated from all other areas. This idea was formed because of the great differences in depth to production in adjacent wells, the numerous dry holes drilled offsetting large wells, and to the fact that offset wells frequently behaved very differently. Now that many of the older pools are practically exhausted and the salt-water level is very near that of the producing horizon, the appearance of salt water in one well is generally followed at an early date by a similar occurrence in all neighboring wells

which are producing from approximately the same depth. The rise of the salt-water level is reasonably uniform in any one pool. The deeper wells begin to show salt water first, and if the pool is being drawn upon heavily water soon appears in the more shallow wells. Almost as consistently, one or two freak wells are found in each pool, which continue to produce clean oil after the others have shown water. Such wells must undoubtedly be producing from reservoirs which extend higher into the structure than the average, and which are connected by fractures to the lower horizons. Given sufficient time, all the wells go to water, and this fact demonstrates that the reservoirs are connected. Due to the difference in size of the various cracks, crevices, or fissures, and the heavy, viscous character of Panuco crude, whose gravity is from 11° to 12° Bé., the relationship between adjacent wells is much less apparent when the reservoir space is filled with oil than it is when this same space is filled with water.

The great quantity of oil which has been obtained from certain wells also indicates a system of connected fracturing. The greatest production from a single well in the Panuco district was obtained from Zurita No. 3, which was drilled a short distance north of the zone of fracturing. This well was not flowed its total capacity during a large part of its history, but during the period from January, 1914, to July, 1924, inclusive, it produced 21,464,170 barrels of oil.

These are the interpretations which have been placed upon the Panuco district, its structure, and the relation between areas of accumulation and certain dynamic features. Before a complete picture can be formulated of this district it is necessary to consider the probable source of the oil. The evidence bearing on this subject, being so closely associated with that which has preceded, will be presented as a part of this dissertation.

PROBABLE SOURCE OF MEXICAN OIL

In the preceding discussion an explanation was given of the factors involved in creating an effective reservoir space for the accumulation of petroleum in a limestone, as interpreted from observations of the conditions which are present in the northern producing district of Mexico. The conclusions thus far reached are that

it is necessary to have the producing horizons, which in this district are composed of limestones, elevated to a relatively high position in relation to the surrounding structure, and also that these limestones must be fractured to create a reservoir space.

Near the northern extremity of the area outlined in Figure 1, and extending a considerable distance northward, are a number of structures which will fulfil the conditions outlined. These are definite, closed structures in which the producing horizons are as high or higher than at Panuco, and which contain fracturing to a considerable extent. Evidence of fracturing, indicated by dikes, is present at many places. These dikes cut across the structures in a general east-west direction, paralleling the zone of weakness. Fractures in the producing horizons themselves can be seen in well samples and cores.

Plate 25, Figure 1, illustrates fracturing at a point in the section which is very near the producing horizon, in a core taken from one of the northern wells. All drilling has thus far been unsuccessful. Salt water is frequently encountered, and also numerous shows of oil, but no commercially exploitable production has been obtained.

In addition to having structures which appear to be favorable for the accumulation of oil, the geological section in the vicinity of the Tamesi, which is the northern part of this area, has not changed, excepting in minor details, from that at Panuco. For these reasons it is apparent that some important factor is lacking. This factor is an adequate source for the oil.

Before discussing the probable source of the Mexican oil there is one other feature that should be borne in mind in connection with the Tamesi district, that is, that the shales from the surface down to the San Felipe are characteristically harder in the most northern part of the district than in the Panuco field. This lithologic feature would act somewhat as a barrier to circulation or migration. Also, most of these shales are sufficiently hard and resistant that any major fracturing which might be present would extend to the surface, and in this manner allow any oil which might accumulate to escape. Because of the absence of evidence in the form of seepages or asphalt deposits at the surface, the writer assumes that no great amount of oil has ever accumulated. In those parts of Mexico where

any considerable amount of petroleum has accumulated there is practically always surface evidence of such accumulation in the form of oil seepages, asphalt deposits, or, occasionally, gas seepages, wherever such areas are crossed by, or contain, dikes, plugs, or major faulting. The lack of such evidence is a characteristic feature of the area under consideration.

One of the most striking features, from the point of view of a petroleum geologist, of the geological column of Mexico as present in the oil fields is the absence of carbonaceous matter. Most of the oil-producing horizons in the United States have, somewhat closely related to them, considerable thicknesses of carbonaceous formations which are generally considered to be the source of the oil. If all the black shales in the geological section at Panuco were grouped together the thickness would generally be less than 5 feet, surely less than 10 feet. There are from 5 feet to several hundred feet of carbonaceous limestone associated with the black shales, but the actual amount of carbonaceous matter is very small.

However, there is present in the Upper Cretaceous and Lower Tertiary of Mexico a prolific fauna of Foraminifera. The author is of the opinion that most, if not all, of the oil from the present producing fields of Mexico has been derived from Foraminifera. The most abundant faunas occur in the basal Eocene, the Velasco, and the Upper Mendez formations. The abundance gradually decreases going downward in the section to the basal San Felipe, below which there are very few individuals in addition to barren beds.

The most important production in Mexico has been obtained from relatively high structures adjacent to faults or faulted belts, on one side of which the upper part of the section, containing abundant foraminiferal faunas, has been faulted downward and protected from erosion, or from "higher structure" adjacent to a deep syncline which contains a considerable thickness of these formations, rich in Foraminifera. Deep production has been obtained from a few areas which are overlain by considerable thicknesses of younger foraminiferal beds, and in which the producing horizons have been fractured by intensive folding or by igneous plugs. These conditions hold true for both the north and south fields.

No large amount of production has ever been obtained from a

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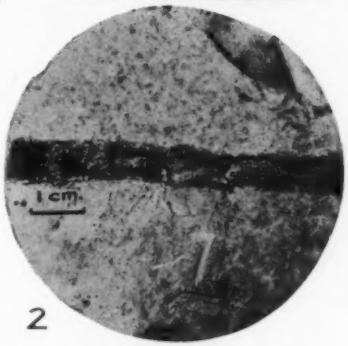

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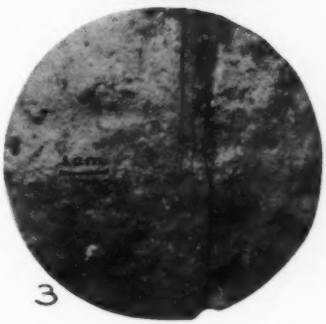

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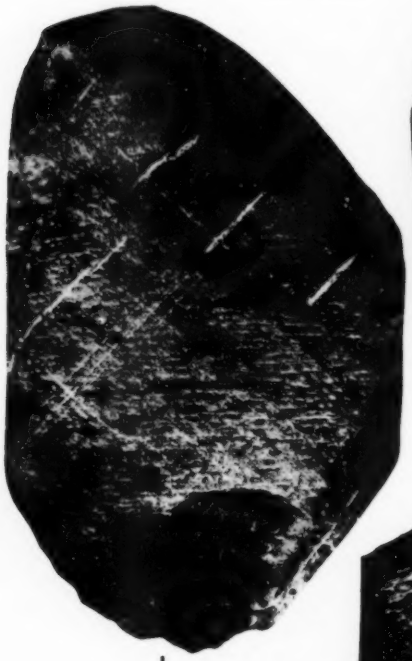

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structure located in an area which is regionally overlain by Mendez or older beds. The presence of these beds alone in a region does not indicate as much as a possibility of commercial production. In addition to a source for the oils, a reservoir space is needed for accumulation, and, equally important, the beds which contain the source of the oil must be placed in a favorable position for accumulation, in relation to those which are to act as a reservoir. This is most effectively accomplished by faulting. The present fields have produced the greatest quantities of oil near faulting or faulted zones which have elevated a reservoir space with respect to beds which contained a source for petroleum. The greater the amount of this relative movement, other factors being equal, the greater the amount of accumulation.

SUMMARY

The following conditions are considered by the writer to be necessary for the accumulation of petroleum in commercial quantities in Mexico:

High structure is very important, but not all-important.

The producing horizons, being limestone, which, in the Panuco district, contain no appreciable reservoir space as a result of weathering or solution, must be sufficiently fractured to form an adequate reservoir space.

The reservoir space must be sealed in such a manner that any petroleum which may accumulate does not escape.

The structure, with an effective reservoir, must be located in a region which contains formations having a source for the oil. Foraminifera are considered to have been the source of the petroleum which has accumulated in the present known fields.

The structural relation between the source horizons and the reservoir space must be such as to permit migration between the two, otherwise there will be no accumulation of petroleum.

EXPLANATION OF PLATES

PLATE 24

FIG. 1.—Typical Upper San Felipe mottling.

FIG. 2.—Core sample showing texture of Panuco gray limestone (Lower San Felipe), which is the most important producing horizon in the Panuco district.

FIG. 3.—Oil-filled fractures in basal Upper San Felipe limestone.

FIG. 4.—Oil-filled crevice in Panuco gray limestone.

FIG. 5.—Band of fragmental material in Upper San Felipe limestone.

PLATE 25

FIG. 1.—Core of basal Lower San Felipe showing steep dip and calcite-filled fractures.

FIG. 2.—Slickensided surface of the most basal Lower San Felipe limestone.

FIG. 3.—Core of basal Lower San Felipe showing steep dip and thin black shale partings.

FIG. 4.—Typical Papagallos crop taken at river bank west of Valles.

DISCUSSION

W. A. M. VAN DER GRACHT: Is the Jurassic which is rumored to have been reached below surprisingly little "Tamasopo" in the Panuco field the black Jurassic?

MR. TRAGER: No, the Jurassic discovered below the Tamaulipas limestone northeast of the town of Panuco is a white, sandy, crystalline limestone containing Ammonites. Its age was determined by these Ammonites.

DR. VAN DER GRACHT: I wish to call attention to a possible very great complexity of structure in this region. It looks like a simple, undulating, and moderately broken monocline, but the wells reveal a very puzzling variety of limestones instead of the old uniform "Tamasopo." The El Abra scarp does not seem to be a simple fault: a well at Guerrero, just to the east, shows no El Abra limestone, but Tamaulipas instead. The Tuxpam fields are producing from El Abra limestone. There is no trace of this limestone at Panuco, but Tamaulipas occurs instead.

At Micos we find the front of the cordilleras; a typical Alpine thrust sheet on which the facies of all the rocks is entirely different (exotic). The whole problem reminds me of former work done along the northwestern slope of the Caucasus, where also an apparently simple, undulating Tertiary monocline proves distressingly complicated at depth, where *Klippen* of Cretaceous (and older?) rocks in the Tertiary indicate plunging sheet fronts. The monocline of the east coast of Mexico may well bring many surprises of a tectonic nature. The more we learn about it, the more complex it becomes.

THE RELATION OF FORAMINIFERA TO THE ORIGIN OF CALIFORNIA PETROLEUM[1]

THOMAS F. STIPP
Pacific and Associated oil companies
San Francisco, California

ABSTRACT

Diatoms have long been considered by many writers to have been the source of the California oil. Recently it has been suggested that Foraminifera, whose tests are found in abundance in rocks closely associated with the oil, may have been an important source of the oil. Recent studies of the life history of the Foraminifera show that a very large proportion of the tests present in the strata as fossils may have been empty of animal tissue at the time of burial. This and other related facts make it appear probable that Foraminifera have been of less importance than diatoms as sources of the petroleum of California.

Diatomaceae are generally regarded by geologists as being the source of most of the petroleum of California. In 1867 J. D. Whitney, in a paper read before the California Academy of Sciences, called attention to the organic origin of the oil of the Pacific Coast. The following is quoted from his paper:

In conclusion, it may be remarked that the marine infusorial rocks of the Pacific Coast, and especially of California, are of great extent and importance. They occur in the coast ranges, from Clear Lake to Los Angeles. They are of no little economical, as well as scientific, interest, since, as I conceive, the existence of bituminous materials in this state, in all their forms, from the most liquid to the most dense, is due to the presence of infusoria—the proofs of which statement I will, at some future time, endeavor to set before the Academy.[2]

Diatomaceae at that time were classed with the Infusoria, their distinction not then being clear. It is evident from the context of the article that Whitney referred to the Diatomaceae as being the source of the petroleum. Whitney's paper is especially interesting

[1] Read before the meeting of the Pacific Section of the American Association of Petroleum Geologists, November 19, 1925, San Francisco, California.

[2] J. D. Whitney, "On the Fresh-Water Infusorial Deposits of the Pacific Coast, and Their Connection with the Volcanic Rocks," *Proceedings of the California Academy of Sciences*, Vol. 1 (1854–68), p. 324.

as being perhaps the first published account of the organic origin of the oil of California.

The diatom theory is now accepted by many geologists. Several writers on California geology have, however, indicated their belief that Foraminifera have contributed to the origin of the oil. Many of the Cretaceous and Tertiary strata of California are rich in fossil Foraminifera, and their close connection in some cases with diatomaceous strata and their proximity to producing oil fields have led geologists to the foregoing natural conclusion.

Recent study and experiments conducted upon Foraminifera tend to show that they have contributed less to the origin of oil than has been believed.

Arnold and Anderson, discussing the origin of the petroleum of California, stated the following in their bulletin on the Coalinga District:

> The oils of the Coalinga district are believed to have been derived from two different sources, namely, the organic shales forming the uppermost member of the Chico (Upper Cretaceous) and those described as the upper portion of the Tejon (Eocene). It is believed that the oil originated from the organic matter, both vegetable and animal, once contained in these beds. The shales are composed in large part of the tests of Foraminifera and diatoms, and a smaller number of other organisms, in such abundance as fully to warrant the assumption that the animal and vegetable material that must have been contained in them when deposited was adequate for furnishing a quantity of hydrocarbons and other compounds more than equivalent to the quantity of petroleum found in this field.[1]

Anderson and Pack, referring to the origin of oil in the foothill region north of Coalinga, indicate clearly their belief that Foraminifera contributed to the origin of the oil, although they consider the Diatomaceae of most importance. Quoting from their writing:

> The oil-bearing zones of this region are the two diatomaceous and foraminiferal shale formations—the Moreno (Upper Cretaceous) and the Kreyenhagen (Oligocene?) and the sandy beds lying immediately above them. This fact points significantly to the two formations as the sources of the oil, and the writers firmly believe that the petroleum was derived from the organic matter

[1] Ralph Arnold and Robert Anderson, "Geology and Oil Resources of the Coalinga District, California," *U. S. Geol. Survey Bulletin* 398 (1910), p. 188.

once contained in the myriad shells of minute organisms of which these formations are largely composed.[1]

It is further stated:

It cannot be said whether both the diatoms and the Foraminifera, or only one of these types of organisms, furnished the organic matter from which the oil was produced, or which was the more important, but it seems probable that both contributed, with the possible addition of ingredients from still other organisms. Owing to the fact that the organic substance of plants is less readily decomposed than animal matter and would therefore be more certain to persist within the deposit until well buried and sealed, the diatoms are believed to have been the greatest contributors.[2]

Pack writes of the origin of the oil of the Sunset-Midway field as follows:

The chief reservoirs of petroleum in the Sunset-Midway district are the feebly consolidated sandy beds of the McKittrick group, but the petroleum is believed to have originated not in these beds, but in the fine-grained beds of organic origin that make up so large a part of the Maricopa shale and of the upper portion of the Vaqueros formation in certain parts of the region. These fine-grained beds are chiefly the so-called diatomaceous shales, which are composed in large part of the remains of minute plants and animals—diatoms and Foraminifera—and it is from the decomposition and alteration of these organisms that the petroleum now found in the Sunset-Midway field results. In parts of the region the organic material contained originally in the fine-grained beds appears to be not so much the remains of diatoms as of larger terrestrial vegetation, and it is probable that part of the petroleum has been formed by the alteration of this coarser vegetal material. But in any case it seems clear that the ultimate source of the petroleum is the organic material originally contained in these beds.[3]

Vander Leck writes:

The diatoms and Foraminifera lived at the surface of warm inland seas, such as were present in what is now the great valley and coast regions of California, during the various geological ages from the Cretaceous to the present.

[1] Robert Anderson and Robert W. Pack, "Geology and Oil Resources of the West Border of the San Joaquin Valley North of Coalinga, California," *U. S. Geol. Survey Bulletin* 603 (1915), p. 194.

[2] *Ibid.*, p. 199.

[3] R. W. Pack, "The Sunset-Midway Oil Field of California," *U. S. Geol. Survey Prof. Paper* 116 (1920), p. 70.

These organisms, dying, dropped to the bottom of the sea and, together with other plant and animal matter, formed an ooze or organic mud. Then, due to low temperature and absence of oxygen in quantities, a very slow decomposition or putrification of the organic parts took place. It is, however, believed that no great quantity of liquid hydrocarbons were formed at this stage. These are believed to have formed when, due to earth movements, the mud or ooze was uplifted above the surface of the sea and, by reason of the heat and pressure due to these movements and possibly aided by the action of saline waters, distillation of the shale took place, which resulted in the formation of petroleum.[1]

The above statements imply clearly the belief that Foraminifera were of considerable importance in contributing to the origin of the oil of California. This belief is based upon the following assumptions: (1) That Foraminifera were present in the Cretaceous and Tertiary seas in large numbers; (2) that the conditions of sedimentation were such as to bury a large proportion of the animal tissue along with the tests of the Foraminifera; and (3) that this animal tissue was wholly or in part converted into petroleum by the agency of pressure, heat, and chemical or bacterial action.

Concerning the first and third of these assumptions little need be said. Foraminifera were doubtless present in large numbers in the Cretaceous and Tertiary seas, as shown by the numerous fossil occurrences. Furthermore, it is reasonable to believe that a part, at least, of the animal tissue of Foraminifera may have been converted into petroleum by suitable reactions. That a large amount of animal tissue was actually buried in the strata, is, however, open to question. The following evidence is presented for the reason that it throws some light upon this problem.

Joseph A. Cushman, an American authority on Foraminifera, writes of their life-history as follows:

When the animal (microspheric form) attains its adult stage, there is a great increase in the number of pseudopodia, and the entire protoplasm either leaves the test and accumulates about the exterior or is drawn into the outer chambers. Finally, each nucleus gathers a mass of protoplasm about itself and secretes the proloculum of a new test. The newly formed proloculum is of the larger type, and is the first chamber of the megalospheric form, instead of being of the same size as that of the microspheric parent from which it was derived. The megalospheric form differs from the microspheric in having a single nucleus. This does

[1] Lawrence Vander Leck, "Petroleum Resources of California," *California State Mining Bureau Bulletin* 89 (1921) p. 13.

not divide, but moves along as new chambers are added, keeping in about the middle number numerically. Nucleoli appear in increasing numbers as the growth continues, and finally the whole nucleus breaks down and a great number of minute nuclei appear. These draw about themselves portions of the protoplasmic mass, and then divide by mitotic division. Finally the mass leaves the test in the form of zoöspores. These are then supposed to conjugate and to give rise to the small proloculum of the microspheric form, thus completing the life-cycle, although the actual process of conjugation has not definitely been observed in this group. The empty tests left behind must form a large proportion of the dredged Foraminifera.[1]

Recently Cushman conducted some experiments in the Tortugas region of the Gulf of Mexico with living Foraminifera. One observation is significant in this connection:

One important observation was that in the case of *Iridia diaphana* taken from *Posidonia* leaves and placed in Petri dishes overnight. In the morning some of these were found to have left their tests empty and were moving about as naked masses of protoplasm with a free and comparatively rapid movement. That the animal may leave the test and pass some time without one is very significant from the standpoint of the method of growth. Growth of the test in those species which have a single chamber has often been a subject of speculation. If the test can be abandoned at will and another secreted or made by collecting more material in the case of those which have agglutinated tests, this difficulty is solved, and we may also understand how various sedentary species can collect various materials which are not common for their tests.[2]

It appears from the above discussion of the life-history of the Foraminifera that a very large portion of the tests preserved in the strata as fossils were empty of animal tissue at the time of burial. It is no doubt true that tidal action—ocean currents—decreases in the salinity of the waters, or other factors impose upon Foraminifera conditions at times unfavorable for their existence, and that many may thus be killed and their tissues within their tests entombed. Some oil may have formed under these conditions. However, to account for the widespread destruction of foraminiferal life and the accumulation and entombment of the animal tissue, such as would be necessary for the formation of oil in quantity, we must postulate

[1] Joseph A. Cushman, "Monograph of the Foraminifera of the North Pacific Ocean," *U. S. National Museum Bulletin* 71 (1910), p. 7.

[2] Joseph A. Cushman, "Shallow-Water Foraminifera of the Tortugas Region," *Carnegie Institute of Washington, Vol.* 17 (1922), p. 8.

unusual and extraordinary conditions of sedimentation recurring at intervals during and since Cretaceous time. Such conditions would lead to a sufficient accumulation of calcareous foraminiferal tests to form considerable thicknesses of limestone, which are unknown in the Cretaceous and Tertiary formations of California. The fact that we do have several thousand feet of diatomaceous strata is considered strong support of the diatom theory. It appears probable from the above that Foraminifera have been of less importance than diatoms with respect to the origin of the petroleum of California.

November 18, 1925

DIAMOND DRILLING NEAR KERENS, NAVARRO COUNTY, TEXAS

F. W. DeWOLF AND PAUL T. SEASHORE
Humphreys Corporation, Houston, Texas

INTRODUCTION

Operations near Kerens, northeast of the Powell field, on the East Bazette structure, were begun in the spring of 1924 by the Boyd Oil Company now Humphreys Corporation, and three deep wells, whose locations were based on surface geology, were drilled in the Morris Webb Survey (see Plate 26.) The first well, Conner No. 1, was completed as a gasser; the next, McCown No. 1, was dry, although a good oil sand had been cored; and the third well, McCown No. 2, was dry. Because of lack of surface outcrops, diamond drilling was then undertaken for determining the extension of the structure. Later, additional deep drilling, done by several companies, confirmed the structure as outlined by the core drilling, although no commercial oil field was obtained.

This paper is a brief history of the work and a record of a successfull diamond-drilling operation. The main points to be covered include the surface structure, the first rotary operations, the diamond-drilling results, the later drilling, and finally, the efficiency and cost of the diamond-drilling operations. The details of the geology will be omitted.

The paper is a summary of work by the geologic staff of the Boyd Oil Company, now the Humphreys Corporation. The surface work was done largely by Edward B. Stiles, assisted by Paul T. Holland, and the study of cores, chiefly by Paul T. Seashore, assisted by Boyd Rowland. Field work was supervised and checked by Sidney A. Judson, F. Julius Fohs, and F. W. DeWolf, in varying degrees and amounts.

SURFACE STRUCTURE

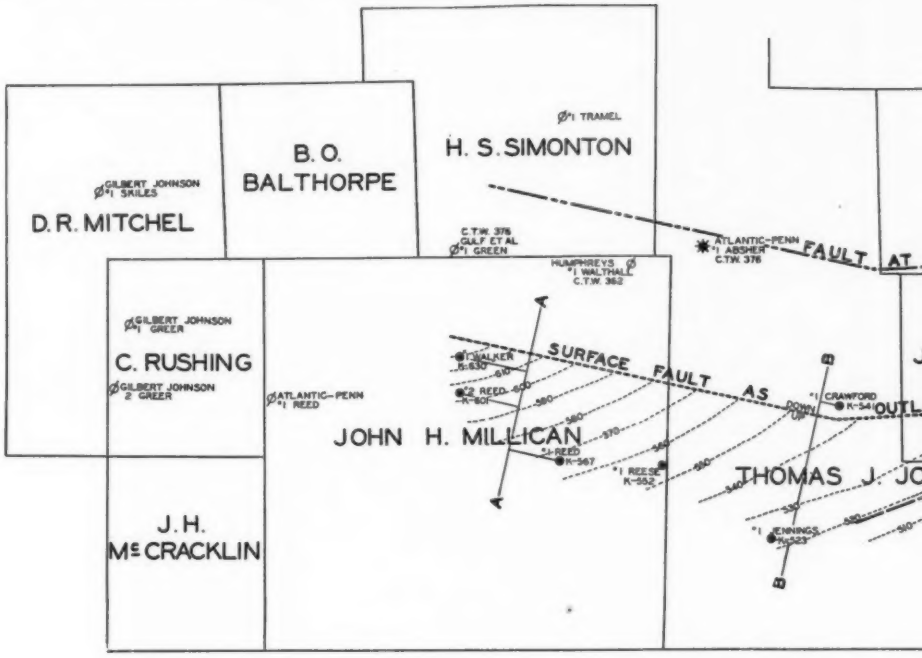
The surface rocks, belonging chiefly to the Midway formation, are exposed in the banks of Trinity River, just north of the area

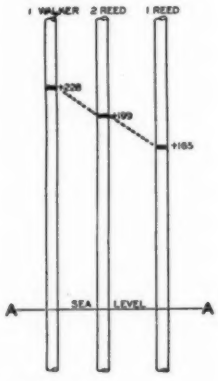
shown by Plate 26, and in the tributary ravines and the upland cotton fields. The section contains a number of beds of limestone or of limestone concretions which, in several instances, have lithologic characteristics that permit identification and correlation. Detailed plane-table work revealed that the beds were dipping gently to the southeast, but that repetition of beds and local steep dips indicated faulting. The chief fault trace, shown by the heavy solid black line on Plate 26, is zigzag. The dashed continuation of this line represents a supposed, but later disproved, extension of the fault to the southwest. The solid-line contours for the eastern part of the area (Plate 26) are based on the surface work, as referred to a key bed, K. They indicate a maximum displacement of approximately 250 feet, with the upthrown block on the southeast. Two minor faults are also shown on Plate 26.

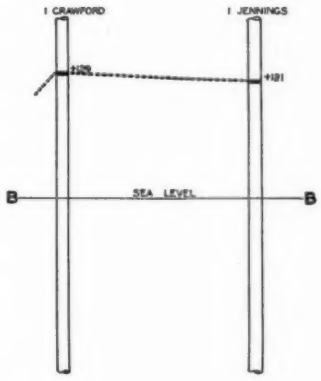
The main fault was considered to be of the Mexia type, offering closure on the northwest, while the surface contours indicated closure to the northeast of at least 140 feet. The first contouring was parallel to the fault trace near the supposed crest of the structure in the Morris Webb Survey, rather than diverging, as shown on Plate 26, and as a result of this interpretation a closure on the south was considered probable.

FIRST ROTARY DRILLING

The location of the first test, Conner No. 1, was made on the assumption that the fault plane dips about 45° and that the Woodbine sand would be reached about the same distance below the surface key bed, as had been computed at Powell. We recognized that some divergence might be expected in a northeast direction and that the Woodbine might be deeper, but hoped to reach it at about 2,930 feet. This would have been a subsurface position comparable to that in the discovery wells at Powell. The test was located about 2,300 feet northwest of the surface fault and about 600 feet east of the estimated position of the fault at the top of the Woodbine (see Plate 26). It actually reached the Woodbine at 3,115 feet, and was completed as a 5,000,000-foot gas well at 3,190½ feet. The contour number for the top of the Woodbine above a datum plane of −3,000, was 228, compared with 410 at the north end of the Powell field. The gas production seemed to confirm the closure on the struc-







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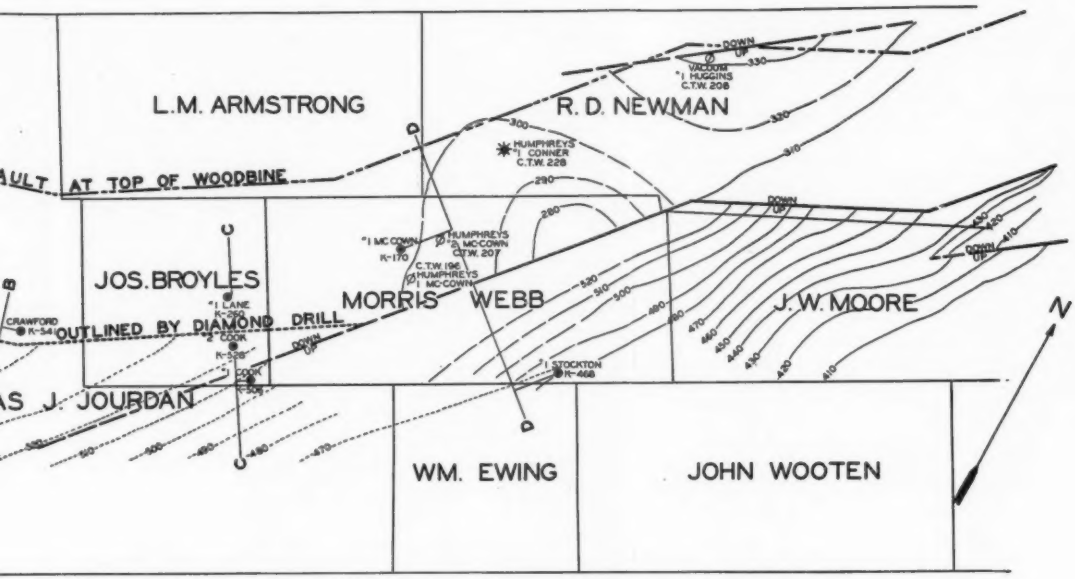

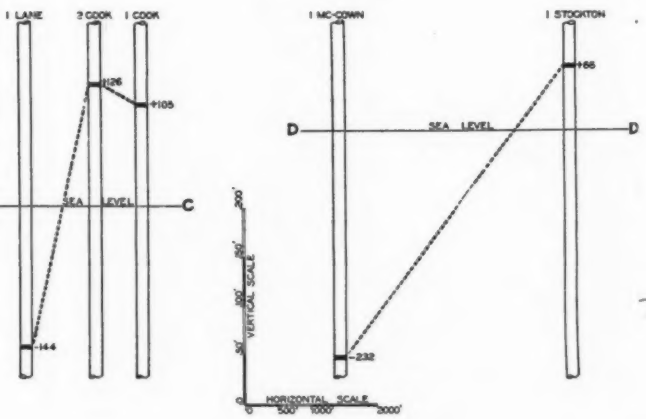

MAP AND SECTIONS
EAST BAZETTE STRUCTURE
NAVARRO COUNTY
TEXAS

SHOWING SURFACE GEOLOGY, DIAMOND DRILL HOLES, AND DEVELOPMENT.

BY- F.W. DEWOLF & PAUL T. SEASHORE

0 1000' 2000' 3000' 4000' 1 MILE

520- = STRUCTURAL CONTOURS REFERRED TO SURFACE KEY BED- SEA LEVEL DATUM.

510- - = STRUCTURAL CONTOURS FROM CONTACT BED REFERRED TO SURFACE KEY BED.

C.T.W. 376 = CONTOUR NUMBER TOP OF WOODBINE FORMATION REFERRED TO DATUM PLANE 3000' BELOW SEA LEVEL.

● DIAMOND DRILL TEST. ✱ GAS WELL. Ø DRY HOLE.

ture, and so McCown No. 1 was located down dip with the hope of obtaining oil. It reached the Woodbine 32 feet lower than Conner No. 1, and cored sand with good oil saturation, but was finished as a dry hole with salt water. McCown No. 2 was given an intermediate location and reached the Woodbine 11 feet higher than No. 1. It was completed with cable tools and had insignificant showing of oil or gas.

DIAMOND DRILLING FOR STRUCTURE

In the absence of outcrops, diamond drilling was begun, following the rotary drilling, in an effort to trace the extension of the surface fault and with the hope of finding a substantial closure on the southwest. The E. J. Longyear Company furnished two No. 1 "N" gasoline-driven drills and did the drilling on a footage contract. The first three holes, Cook No. 1 and No. 2 and Jennings No. 1, were located on the assumption that the surface fault continued in a straight line (see heavy dashed line, Plate 26), but all reached the glauconitic contact bed between the Midway and Navarro formations at about the same position. The contour numbers referred to the key surface bed were, respectively, 506, 528, and 523. The fourth hole, Lane No. 1, reached the contact bed at a contour number of 260 and indicated a minimum downthrow of 268 feet and a decided change in direction of the fault. Later drilling included holes on the Stockton lease beginning on one of the surface key beds, and on the McCown land near the rotary wells, in order to verify the intervals between surface and shallow subsurface key beds. Work then proceeded westward until eleven holes had been drilled. Cross-sections showing the position of the contact bed in ten of these are given on Plate 26. The displacement shows clearly in cross-sections D–D and C–C. In B–B, the Crawford test crossed the fault just below the contact bed, as indicated by lithologic change in formations and by crumpled and slickensided beds. In A–A the fault was not crossed, unless at a very shallow depth.

The structure, as revealed by the diamond drilling, is also shown on Plate 26, the heavy dotted line representing the trace of the surface fault, and the dotted contour lines, the structure on the contact bed as referred to the surface key bed.

LATER ROTARY DRILLING

The diamond drilling made it evident that the fault had changed direction decidedly and would be related to another surface fault which was believed to exist near the Atlantic–Penn–Reed dry hole and have a southerly trend toward the Powell field. This, however, was believed to be distinct from the Powell surface fault. It seemed likely that the looked-for closure on the East Bazette fault might occur north of the Atlantic-Penn well, due to the lapping over of the two faults, or, in case they were the same fault, in the angle

TABLE I

STRUCTURAL DATA FROM DIAMOND-DRILL TESTS ON EAST BAZETTE STRUCTURE, NAVARRO COUNTY, TEXAS

Well	Elevation (Feet)	Navarro Contact (Feet)	Contour Number, Navarro	Contour Number, K Bed
Cook No. 1	404.8	300	3,104	506
Cook No. 2	404	278	3,126	528
Jennings No. 1	390	269	3,121	523
Reese No. 1	389	239	3,150	552
Stockton No. 1	366.4	300.4	3,066	468
Lane No. 1	409.7	552 (?)	2,857.7	259.7
Crawford No. 1	393	264 (est.)	3,129 (est.)	541*
Reed No. 1	372.4	207	3,165.4	567
Reed No. 2	362.0	163	3,199	601
Walker No. 1	363.8	136	3,227.8	629.8
McGowen No. 1	375.9	608	2,768	170

* Crossed fault at 264 feet.

where the change in direction would occur. Unfortunately, lack of leases farther west prevented more core drilling to test this theory. Our Walthall test was located with the hope that it might be at least a good east-edge well, but it was completed a dry hole; the nearby Atlantic–Penn–Absher was a light gas and salt-water well; and the Gulf-Green was also dry. Other later drilling to the south has also been unsuccessful. The position of the surface fault, as determined by coring, was approximately checked by the rotary drilling. And just as the surface beds on the upthrown block continued to rise in a southwest direction, the Woodbine sand had a similar rise, though about 35 feet less in the distance from the Conner to the Walthall well.

TABLE II

SUMMARY OF DIAMOND CORE DRILLING ON EAST BAZETTE STRUCTURE, NAVARRO COUNTY, TEXAS

Test	Total Depth (Feet)	Drilling Time (Hours)	Average Footage (Per Hour)	Drilled by Fishtail Bit (Feet)	Drilled by Diamond Bit (Feet)	Core Recovered (Feet)	Percentage of Recovery	Total Cost	Cost per Foot
McCown No. 1	619	413	1.499	20	596	460	77.2	$ 1,949.00	$3.15
Cook No. 1	346.5	347	.997	17	329	259	78.7	1,436.75	4.15
Cook No. 2	312	144	2.167	23	289	233	80.6	998.16	3.20
Jennings No. 1	313.5	154	2.032	25	268	213	79.5	1,076.85	4.44
Reese No. 1	303	140	2.164	20	277	219	79.1	1,226.21	4.05
Lane No. 1	671	428	1.568	20	532	390	73.4	2,529.79	3.77
Stockton No. 1	302	162	1.864	10	253	153	60.4	1,102.20	3.65
Crawford No. 1	344	199	1.729	?	225	182	80.9	1,558.57	4.53
Reed No. 1	253	131	1.931	17	232	190	81.8	955.29	3.78
Reed No. 2	174	87	2.000	23	151	122	80.8	567.10	3.26
Walker No. 1	162	79	2.051	17	138	93	67.4	590.00	3.64
Totals and averages	3,800	2,284	1.664	192	3,290	2,514	76.4	$13,989.92	$3.68

EFFICIENCY AND COST OF DIAMOND DRILLING

The Longyear Company undertook the work without previous experience in the region, and therefore at a price per foot which could not be based on a close knowledge of probable cost. The accompanying table (Table I) shows in detail for each hole, the depth, drilling time, footage per hour, core recovery, cost per foot, and total cost. The holes measured a minimum of 162 feet, a maximum of 671 feet, and an average of 345 feet. The core recovery, excluding that part of each hole drilled with fishtail bit, varied from 60.4 per cent to 81.8 per cent, and averaged 76.4 per cent. The cost per foot varied from $3.15 to $4.53, and averaged $3.68. It is proper to state that the price paid was based on a sliding scale according to total footage, and that the last drilling was at a rate much less than the rate at the beginning. On the whole the work done and the basis of settlement were quite satisfactory to our company.

WERE DIATOMS THE CHIEF SOURCE OF CALIFORNIA OIL?

GEORGE M. CUNNINGHAM
Fullerton, California

ABSTRACT

California has occupied a peculiar position among the petroliferous provinces of the United States in having formations associated with the oil-bearing rocks which, from the content of microscopic organisms, obviously might have been the source of the oil. This has led to the general acceptance of the theory that of these organisms, the diatoms, which occur in greatest abundance, provided the greater part of the organic material which was altered to form the petroleum of the major oil fields of the state.

Recent work has shown that the organic shales in other petroliferous provinces do not necessarily contain recognizable fossil remains, and that organic material carried into the basins of deposition by rivers and precipitated by saline waters, is an adequate source for the petroleum of our oil fields. Decay-resistent vestiges of plant and possibly animal remains may have contributed to the supply.

The shales within the oil zones of the fields of southern California have many characteristics which suggest that they may have been the source of the oil now contained in the sandy beds with which they are interbedded. The present position of the oil in the Pliocene section and the distribution of the oil in the anticlinal structures in the Los Angeles basin point to the Pliocene sediments, which are relatively free from diatoms, as the source rocks. This hypothesis seems to fit the observed conditions in southern California fields better than the diatom theory.

HISTORICAL REVIEW

For the past fifteen years diatoms contained in the shales of the Monterey series of Miocene age have been regarded as the primary source of the oil of the major oil fields of California. This conclusion was reached by the early workers in the state from the obvious fact that these shales are associated with the rocks which contain the oil in most of the known fields.

In having a specific geologic formation established as the original source of the oil, California was, for a number of years, relatively alone among the petroliferous provinces of the United States. In 1911 Campbell[1] considered it questionable whether a review of the theories advanced to account for the origin of petroleum was worth making, except to show that geologists and chemists were actively endeavoring to solve the problem.

[1] Marius R. Campbell, "Historical Review of the Theories Advanced by American Geologists to Account for the Origin and Accumulation of Oil," *Econ. Geol.*, Vol. 6 (1911), p. 363.

This condition, however, did not apply to California at that time. Campbell considered that for California, at least, the problem had been solved. To quote from his paper:

> Fortunately, there is one place in this country where it has been possible practically to solve the question of origin, and since this is such a great exception and so important of itself the writer will be pardoned if he goes rather fully into a description of the conditions. The region in question is California and the conclusions here are the results of the work of Messrs. Arnold, Anderson, and Johnson.
>
> The studies of these geologists have shown that without much doubt foraminiferal and diatomaceous shale is the source of the California oil.

This conclusion of Arnold, Anderson, and Johnson regarding the origin of the oil of California was reached after a study of the Santa Maria and San Joaquin Valley oil fields. In regard to the oil of Santa Maria, Arnold and Anderson said:

> The general conclusion is that in the Santa Maria district the organic material in the Monterey shale which may have acted as the source of the oil was without doubt adequate in amount for the production of the vast quantity of petroleum now present, and that the forms included in greatest abundance, the diatoms, were the chief source, although animals and perhaps plants also contributed largely.[1]

In the McKittrick-Sunset region Arnold and Johnson reached a similar conclusion: "The organic matter in the Monterey shale is believed to be the source of at least a part of the oil in the McKittrick-Sunset region; its presence, or that of the Santa Margarita (?), is therefore believed to be necessary for the accumulation of petroleum in this territory."[2]

This theory was accepted by Pack in later work in the San Joaquin Valley. In summarizing the results of his work he says: "The petroleum has originated in the diatomaceous shale formations, chiefly from the alteration of organic matter contained in diatoms and foraminifers, but probably in part also from the alteration of terrestrial vegetal débris."[3]

[1] "Geology and Oil Resources of the Santa Maria Oil District," *U. S. Geol. Survey Bulletin* 322 (1907).

[2] Ralph Arnold and Harry R. Johnson, "Preliminary Report on the McKittrick-Sunset Oil Region, California," *U. S. Geol. Survey Bulletin* 406 (1910).

[3] R. W. Pack, "The Sunset-Midway Oil Field, California," *U.S. Geol. Survey Prof. Paper* 116 (1920), p. 10.

Having accepted this hypothesis he was forced to conclude that some of the hydrocarbons which now form a tar zone about 1,000 feet above the oil-bearing rocks migrated more or less vertically through 2,000 feet of sediments. Apparently recognizing the improbability of migration of oil in this manner, he concluded that the hydrocarbons migrated in a gaseous state.

Although the diatom theory for the origin of the oil of California was first applied to the Santa Maria and San Joaquin Valley fields, it has been given a much wider application. S. H. Gester says of the Huntington Beach field:

> The origin of most of the oil in the Huntington Beach field is undoubtedly from the Puente shales underlying the reservoir beds of the Fernando. Like all Middle Miocene shales of California, the Puente in this district is an organic shale largely made up of diatoms which could quite likely be the source of all the oils in the field. However, the lower shales of the Fernando contain considerable organic material and may contribute to the supply.[1]

Arnold reiterated his former statements regarding the origin of the oil of California in 1923: "George H. Eldridge, Robert Anderson, Harry R. Johnson, and the writer, in their work in the California oil fields, have clearly demonstrated that the principal sources of oil in California are free-swimming, microscopic, unicellular marine plants called diatoms, many millions of which occupy a cubic inch."[2]

POSSIBLE SOURCES OF OIL OTHER THAN DIATOMS

The foregoing statements have been quoted in full for the double purpose of stating the diatom theory for the origin of California oil and of showing the extent to which this hypothesis has been accepted.

We must grant that some of the oil of California has originated in the Miocene rocks. At Santa Maria, in parts of the Hovey Hills in Kern County, in the Puente field, and in parts of the Torrance field there seems to be little doubt but that organic material from Miocene shales has been the source of the oil. Whether or not dia-

[1] S. H. Gester, "Huntington Beach Oil Field, Orange County, California," *Bulletin American Association Petroleum Geologists*, Vol. 7, (1924) p. 45.

[2] Ralph Arnold, "Two Decades of Petroleum Geology, 1903–22," *Bulletin American Association Petroleum Geologists*, Vol. 7 (1923), p. 603.

toms were an important factor is an open question. Nevertheless, as will be shown later, there are valid objections to the Miocene beds as source rocks for a great part of the oil now contained in the Pliocene beds of California. Several conditions indicate that much of the oil originated in the Pliocene rocks themselves, and since these beds are relatively free from diatoms, we are forced to look to some other source for the oil.

Although the diatom theory has been accepted almost universally to account for the oil of California, several geologists have recognized that petroleum within the Miocene beds themselves is commonly associated with the cherty, rather than with the diatomaceous, beds.[1] This is the condition at Santa Maria. Walter Stalder[2] has observed petroleum stains in dolomitic shales, together with distinct evidence of petroleum in limestone and dolomites within the Monterey (Salinas) shales. He considered the field evidence to indicate that oil originating in the organic shales is derived from Foraminifera as well as from diatoms, and that it is, therefore, not necessary to have an abundance of diatomaceous shales in any region if the dolomitic or calcareous shales derived from Foraminifera are present.

Since the first statement of the diatom theory much work has been done in identifying the organic material occurring in shales associated with oil deposits. It was found that these organic shales contained a jelly-like, amorphous, flocculent, organic material which some authors called "kerogen,"[3] and which has been considered by some to be the source of oil. Imbedded in this material are often found also the decay-resistent vestiges of plant and animal remains, but it has been fairly well established that these organic shales do not necessarily contain a great amount of recognizable fossils.[4]

[1] F. D. Gore, "Oil Shale in Santa Barbara County, California," *Bulletin American Association Petroleum Geologists*, Vol. 8 (1924), p. 463.

[2] Walter Stalder, "A Section of the Monterey (Salinas) Shales in Pine Canyon, Monterey County, California," *Bulletin American Association Petroleum Geologists*, Vol. 8 (1924), p. 55.

[3] Colin Rae, "Organic Material in Carbonaceous Shales," *Bulletin American Association Petroleum Geologists*, Vol. 6 (1922), p. 333; Martin J. Gavin, "Oil Shale: An Historical, Technical, and Economic Study," *U. S. Bureau of Mines Bulletin* 210 (1922); Earl Trager, *Bulletin American Association Petroleum Geologists*, Vol. 8 (1924), p. 301.

[4] Colin Rae, *op. cit.*, p. 335.

The substance called "kerogen" is slowly soluble at ordinary temperatures in organic solvents and forms readily soluble bitumens at high temperatures. Trager's experiments seemed to indicate that readily soluble bitumens could be formed from "kerogen" by subjecting the organic shales to pressures sufficient to produce rock flowage. Later work by Van Tuyl and Backburn[1] casts doubt on the correctness of this conclusion, since it was not found possible to produce free oil from the "kerogen" of oil shales at temperatures which would normally exist at a depth of more than 8,000 feet in the earth's crust. It was their conclusion that "kerogen" and petroleum represent different end products of the transformation of organic débris. They suggest that differences in bacterial action at the time of deposition, or some other causes, are important in determining the character of the final product obtained.

Colin Rae[2] came to the conclusion that the organic material of carbonaceous shales is the result of the precipitation, in the presence of sea water and electrolytes, of ulmohumic acids derived from the decomposition of plant and animal remains which are carried to the basin of deposition by river waters. He points out that the analyses of river waters of the present time indicate that millions of tons of humus are carried to the oceans annually and that the streams which carry the highest percentage of humus in the dissolved material are those which drain tropical areas. It is pointed out that sometimes river waters carry 20 to 50 per cent colloidal silica in solution, which likewise would be precipitated by electrolytes along with the humic acids. This last condition seems to have a bearing on the problem due to the association of the oil of the Santa Maria field with the cherty phase of the Monterey shale. A somewhat similar condition exists in the Rocky Mountain states, where the Mowry shale is considered to be the source of the light oil.[3] This shale appears to contain practically no diatoms, is extremely rich in fish scales, and contains a large amount of cherty material which

[1] Francis M. Van Tuyl and Chester O. Blackburn, "The Effect of Rock Flowage on the Kerogen of Oil Shale," *Bulletin American Association Petroleum Geologists*, Vol. 9 (1925), p. 158; "The Relation of Oil Shale to Petroleum," *op. cit.*, Vol. 9 (1925), p. 1127.

[2] Colin Rae, *op. cit.*, p. 340.

[3] W. H. Geis, "The Origin of the Light Oils of the Rocky Mountain Region," *Bulletin American Association Petroleum Geologists*, Vol. 7 (1923), p. 488.

Washburne[1] believes to be the result of precipitation of silica from the sea water, and not due to the alteration of siliceous organisms. Certainly, too, much of the porcelaneous phase of the Monterey series has the appearance of precipitated silica, although published microscopic studies are not available to establish this point.

Black shale now being deposited in and about Chesapeake Bay has been described by Goldman.[2] The accumulation of "black shale" rich in organic material seems to be taking place near the mouths of rivers and is favored by depressions in the bottom of the bay. The flocculation of suspended organic material by greater salinity is suggested as a possible cause of the presence of the black shale. He points out that the presence of this black mud has the effect of producing a high mortality among the fishes in the immediate vicinity. This seemingly has some application to the problem, in view of the great numbers of fish scales noted in the Mowry shale of Wyoming, in parts of the Miocene shales of California, and in the dark shales interbedded with the oil sands in the Pilocene of the Los Angeles basin.

Apparently the conditions which favor the accumulation of large amounts of organic material in sediments are those which are unfavorable to the existence of animal life within the basin of deposition. It has been pointed out that organic shales in general are characterized by a scarcity of littoral or benthonic forms, thinness of shells, and dwarf forms, all being evidence of unfavorable biologic conditions. The small number of pelycepod and gastropod fossils found in the oil zones of the Pliocene of southern California, in contrast with the presence of fossils in the shales of the beds both above and below, therefore, becomes significant.

Pyrite is frequently noted in cores of the oil zones in the southern California fields[3] and may have some bearing on the problem in view of the formation of hydrogen sulphide accompanying the accumulation of organic shales of recent origin and the observed pyritization of shells in older organic shales.

[1] C. W. Washburne, *Bulletin American Association Petroleum Geologists*, Vol. 7 (1923), p. 440.

[2] Marcus I. Goldman, "Black Shale in and about Chesapeake Bay," *Bulletin American Association Petroleum Geologists*, Vol. 8 (1924), p. 195.

[3] G. L. Andrews, oral communication.

APPLICATION TO OIL FIELDS OF SOUTHERN CALIFORNIA

In view of the results of recent work just reviewed, and the absence of petroleum associated with fresh-water diatom deposits, it seems entirely possible that the presence of diatoms in the Miocene shales of California may be entirely incidental to the occurence of the oil. This has considerable application to those fields where the oil has originated, without much doubt, in the Miocene. There is a more important application, however, in several fields of the Los Angeles basin, in that non-diatomaceous shales which are associated with the oil zones of the Pliocene can be considered as a possible source for the oil.

There is a tendency, in theoretical discussions, to consider the oil zones in the southern California fields as solid bodies of sand. Nothing is farther from the truth. The oil zones consist of alternating beds of sand, sandy shale, and shale. Individual beds of sand exposed by continuous coring rarely exceed ten feet in thickness, and the percentage of sand in the oil zones seldom is more than 40 per cent, 25 per cent being a more representative figure.

It has been suggested that organic material from the Pliocene shale bodies within the oil zones in the southern California fields may have been the source of the oil. The relation of the oil zones to the top of the Miocene formations seems to favor this hypothesis. In the Santa Fe Springs field, Pliocene fossils were obtained more than 2,200 feet below the base of the deepest producing zone of the field in the Standard Oil Company's Brownrigg-Keller well No. 2. The productive zones are about 950 feet thick. It is apparent therefore, that the thickness of Pliocene beds below the top of the oil at Santa Fe Springs is at least 3,150 feet. This is a minimum figure, since the deepest well, stratigraphically, stopped in Pliocene beds. In the central part of the field the production is confined to a thickness of 950 feet, and beds for at least 1,500 feet below do not contain more than an occasional show of oil.

A similar condition exists in the Inglewood field, where Pliocene beds occur at least 4,600 feet below the top of the oil.[1] Miocene beds have not been encountered in the deepest wells and the thickness

[1] This figure is based on foraminiferal correlations by H. L. Driver, between wells in the productive area and deep wells east of the fault zone in the Baldwin Hills.

of beds between the top of the oil and the top of the Miocene must be in excess of this figure.

If we are confined to the Miocene shales as the possible source of the oil, how has the oil reached its present position? It seems unreasonable to expect oil to migrate transversely to the bedding through this thickness of sediments in view of the high percentage of impervious shale contained in the section. If such were the path of the migration we should expect the oil zones to be most extensive in, and confined to the beds closest to, the top of the Miocene. Such is not the condition.

In theoretical discussions transverse migration, i.e., across the bedding, is considered to be an important factor in the accumulation of oil, but considering the known conditions in some of the southern California fields it is difficult to assign it more than minor importance. If transverse migration has been the controlling factor it is difficult to understand why accumulation has taken place at all; why all the oil has not escaped to the surface, for tension cracks due to folding, if such there be, would be expected to reach maximum development in the shallower beds.

This opinion that transverse migration is relatively an unimportant factor in the accumulation of oil and gas in southern California is certainly open to argument. However, there is some direct evidence on the subject. In the area from Dominguez Hill to the city of Inglewood a number of wells have encountered dry gas under high pressure at considerable distance above the oil zones. Some spectacular blow-outs resulted. From almost every well where gas occurred, fragments of wood and material resembling pine cones were blown out by the gas. The evidence suggests that all the gas comes from beds in approximately the same stratigraphic position, and that these beds contain material competent to form the gas. This condition suggests that even gas under high pressure does not migrate transversely far from the beds from which it was derived, at least in this particular area. It is difficult to imagine that the oil of the fields of southern California has migrated through thousands of feet of sediments containing a high percentage of relatively impervious beds, in view of the apparent inability of gas under high pressure to migrate transversely to the bedding.

Due to the association of faulting with some of the southern California fields it might be argued that the faults were the avenues of migration of the oil from the Miocene rocks to its present position. The field evidence does not agree with this contention. At Inglewood the fault zone is associated with water troubles, and not with the unusually high productivity which would be expected if the oil of the field had come up along the faults from the Miocene shales below. Neither does production extend a greater distance along the fault zone than would be expected from the general structure of the area. A similar condition exists at Signal Hill, where the most productive part of the field is on the opposite side of the structure from the recognized fault zone.

In the Sunset-Midway district, Pack[1] concluded that the Miocene shales were the source of the oil and that the unconformity at the base of the Pliocene beds was an important avenue of migration. In this regard he says:

> The oil has evidently moved chiefly through the lowest part of the formation that rests upon the diatomaceous shale, as these beds are fairly porous and offer less resistance to the movement of oil than the shale. The movement is therefore chiefly parallel to the plane of the unconformity, that is, to the top of the shale. Near the outcrop, either by fractionation or by reaction with alkaline water, the oil becomes very viscous or tarry, and seals more or less completely the beds through which the oil is moving. When this avenue of escape to the surface is closed, the oil moves out from the plane of the unconformity through the more porous of the beds in the formation that rests upon the shale. The movement of the oil in this manner is rendered easy by the fact that the younger formation was laid down in a transgressing sea, and the different beds in it abut against the shale just as horizontal layers of sand in a huge bowl would rest against the sides of the bowl.

If we were limited to the Miocene shales as the source of the oil of the Los Angeles basin, a similar explanation might be offered to account for the present position of the oil in the Pliocene beds of the basin, for the conditions in the Los Angeles basin are essentially the same as those described by Pack for the basin in the southern part of the San Joaquin Valley.

However, the distribution of the oil in the anticlinal structures

[1] R. W. Pack, "The Sunset-Midway Oil Field, California," *U. S. Geol. Survey Prof. Paper* 116, p. 11.

around the edge of the Los Angeles basin does not accord with this explanation, for, applying Pack's explanation, we should expect the greatest accumulation of oil in an anticlinal structure to be on the side toward the edge of the basin. Such is not the condition in the Southern California fields, for at Santa Fe Springs, Montebello, Signal Hill, and Inglewood the oil extends farther down the side of the structure adjacent to the basin. This last condition in itself, due to the fact that the interval from any bed in the Pliocene to the top of the Miocene increases toward the center of the basin, suggests that the Pliocene beds were the original source of the oil and that the chief migration has been in the Pliocene formations, parallel to the bedding. Such a distribution of the oil as that in the structures in the Los Angeles basin is not uncommon. In fact, in most oil fields we expect production to extend for a greater distance down the regional-dip side of the structure.

It is a commonly accepted rule in California that commercial oil fields are not to be expected in areas where large amounts of diatomaceous shale are not present in the section. This empirical rule has been used as an argument to show that diatoms were the source of the oil, but it has little bearing on the problem, for the Miocene shales are widespread and, in general, must be present wherever there have been large basins of Pliocene deposition. However, exceptions to the rule are known. Miocene shales are absent at Kern River, and in the exposures immediately south of the Richfield oil field there are practically no diatoms in the upper 1,000 feet of the Miocene shales, and a relatively small amount of diatomaceous shale in the entire section.

In conclusion: Recent work has shown that organic shales do not necessarily contain recognizable fossil remains, and that organic material carried into the basins of deposition by rivers and precipitated on coming in contact with saline waters is an adequate source for the petroleum of our oil fields.

The shales within the oil zones of the fields of southern California have many characteristics which suggest that they may have been the source of the oil now contained in the sandy beds with which they are interbedded. The present position of the oil in the Pliocene section and the distribution of the oil in the anticlinal struc-

tures in the Los Angeles basin point to the Pliocene sediments, which are relatively free from diatoms, as the source rocks. This hypothesis seems to fit the observed conditions in southern California better than the diatom theory.

DISCUSSION

HOWARD W. KITSON: In the course of his paper Mr. Cunningham disparages the possibility of transverse migration and states that its proponents do not explain how vertical migration through anticlinal joints becomes arrested, since such joints must extend to the surface, and asks what prevents escape to the surface. I cannot let this statement pass unchallenged, as, to me, transverse migration seems a most natural phenomenon and one that, on theoretical grounds, can be explained step by step in chronological order—especially in California—from the incipience of petroleum in the diatomaceous shales of the Upper Miocene to its accumulation in the Lower and Upper Pliocene.

The theories and evidence involved in transverse migration have been described in various papers published in the *Bulletin*, and a co-ordination of the mechanics of the process with the facts in California surface and subsurface geology is all that will be attempted in this discussion.

Structural and stratigraphic conditions in California are in general as follows:

1. Angular and erosional unconformities exist between the Recent, Pleistocene, Pliocene, and Miocene formations, affording evidence of progressive diastrophism from at least the end of the Miocene to the later Quaternary, along lines of flexure that, for present purposes, may be considered as initiated at the end of the Miocene and protracted successively subsequent to the deposition of each of the younger formations.

2. Organic shales in great abundance, represented by diatomites, occur in the Upper Miocene and relatively much more rarely in the Pliocene, so far as known.

3. Sands and clay shales prevail in the Pliocene and younger formations.

From the evidence it would appear that folding, in pre-Pliocene time, was relatively moderate; but that as time went on and younger beds were laid down, the older formations became more closely compressed by moderate folding of the later sediments. In general, four main periods of renewed folding are indicated; one at each of the four main unconformities recognized.

By the end of Pliocene time, basinward folds in the Miocene would have become more or less deeply buried. Through slow, steady compression and higher temperatures with depth, an effect would be produced analogous to the fatigue of steel or concrete, and yield would be by flowage or semiflowage. Thus Miocene structures would tend to assume a type known as "similar folds."

The transverse compression set up in the flanks of folds of the similar type provides conditions of pressure and temperature which, together with the pri-

mary expulsion of contained connate moisture, would—it is conceivable—be conducive to the metamorphosis of the organic content of the rocks into gaseous and liquid hydrocarbons.

Such nascent oil and gas following the salt-water content would be squeezed out of highly compressed regions and would be forced to migrate to horizons of less pressure. Such a horizon would not be expected to lie in the synclines where greater depth, pressures, and temperatures are conducive to a high state of intersticial compression; but rather would such fluids, especially gas, tend to expand and migrate toward the jointed zones where pressure is relieved along the crests of anticlines. Such a migration would be via sheared bedding planes and interbedded sand members. It would be lateral migration until the axis has been reached.

As folding continued, new supplies of oil and gas from the flanks would force advance accumulations farther and farther upward through the jointed zone at the apex; aided by "gas expansion and propulsion of the oil, even ahead of the salt water."[1]

The question arises: Why do not such accumulations proceed through the joint zone which should extend to the surface and there become dissipated? What is there to arrest vertical migration?

This, or rather this tendency, is exactly what might be expected to take place, but three other important considerations serve to obstruct this otherwise free passage. The first of these is the lessening in intensity of folding of each higher unconformable formation, with consequent less jointing in the arches of each as the surface is approached. The second consideration is the intermittent character of diastrophism and the intervening periods of quiescence when reconsolidation of joints is effected by compression from the weight of superimposed burdens. The third consideration is the process of cementation that takes place for short distances below the ground-water level. This water table of course migrates upward or downward throughout the ages with alternate subsidence and uplift of the region and the relative rates of sedimentation and erosion.

By taking into account the great time element and the alternating periods of joint reopening and recementation, and the generally upward migration of the water table, it sould seem conceivable that the migration of oil and gas under pressure from below would proceed slowly upward intermittently, in stages apace with these conditions.

Stray seepages, by infiltration of the ligher oils through temporarily arresting cap shales, would create isolated lenses of oil characteristic of some of the fields. Ventura Avenue is a good example. Tar sands or heavy oils above the main production zones can be accounted for by the destructive reactions of oil with oxygenated meteoric waters. Both conditions contribute to produce gravity differentiations between zones separated by impervious or semi-impervious

[1] R. van A. Mills, *Bulletin American Association Petroleum Geologists*, Vol. 7 (1923), pp. 14–21.

layers, and the variation in lateral extent of different oil zones is explained by the tendency toward lateral migration of salt water and oil after each arresting stratum is reached.

Whether or not the oils would eventually reach the surface is purely a matter of ratios between the rate of upward migration and the algebraic sums of the rates of sedimentation versus erosion. Undoubtedly some accumulations have escaped, and certain asphaltic surface deposits may be thus explained.

Such processes are far from being impossible or even unlikely, and the evidence afforded by surface and subsurface geology in California is strongly suggestive of transverse migration.

AN EXPERIMENT WITH A DROP AUGER[1]

CHARLES H. ROW
Sun Oil Company, Dallas, Texas

ABSTRACT

This paper describes a means of securing fresh shale samples at comparatively shallow depths in an area covered by sand or other reworked material. A simple, inexpensive, home-made device was constructed for this purpose and proved satisfactory. Costs and general results are given.

INTRODUCTION

The field geologist is often confronted with the problem of determining structural conditions in an area that is completely covered by reworked material. Numerous types of core-drilling equipment have been devised for this work, and each one is best suited to some particular area or to some special kind of work. If shale or soft sandstone beds that can be used successfully for correlation purposes underly an area at comparatively shallow depths, a light, portable apparatus called a "drop auger" will be found useful. This may be classed as a type of core drill.

Some months ago the writer, together with D. M. Collingwood and A. L. Jones, made some experiments with the drop auger. The object in that work was to secure fresh shale samples for microscopic study. Since no great drilling depth was required, the light equipment was considered adequate for the purpose.

DESCRIPTION OF EQUIPMENT

The drop auger used in this experiment consisted of a 12-inch piece of 2-inch pipe, split lengthwise, spread open one-half inch to an inch, and belled and sharpened on one end. The opposite end was welded to an iron shaft three-fourths of an inch in cross-section and 7 feet long. A loop was made in the upper end of the shaft. The tool complete weighed about 15 pounds (Fig. 1).

A tripod constructed with 2×4-inch boards, 14 feet long and braced with 1×4-inch pieces, served as the derrick. An 8-inch iron

[1] Published with permission of the Sun Oil Company, Dallas, Texas.

pulley was suspended in the top of the tripod. A $\frac{3}{4}$-inch rope was then passed over the pulley wheel and tied to the loop of the auger

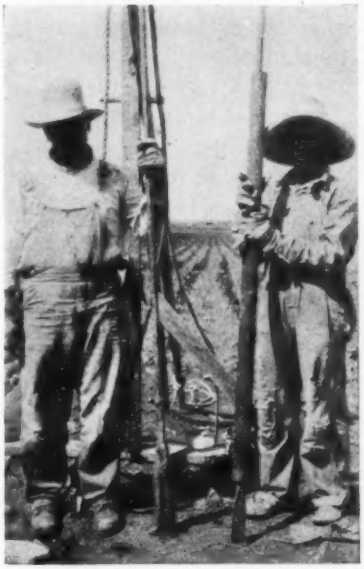

FIG. 1.—Drilling tools

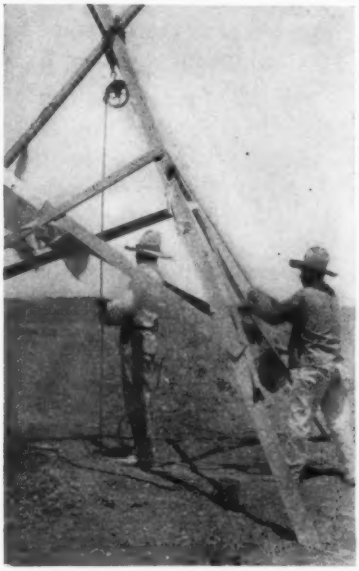

FIG. 2.—Type A rig

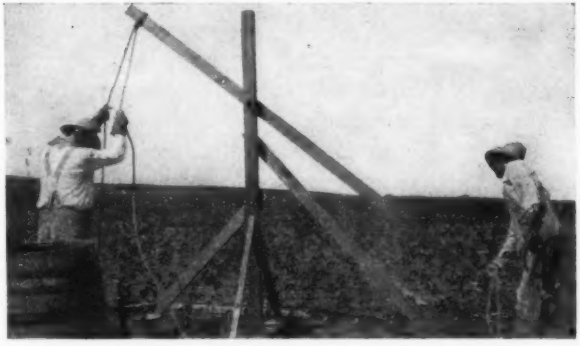

FIG. 3.—Type B rig

shaft (Fig. 2). A barrel of water, bucket, and tub for use in washing samples completed the equipment. The hole was started and drilled to a depth of 6 or 7 feet by the ordinary method of digging post-holes. A 2-foot piece of 4-inch pipe was set in the top of the hole to prevent surface caving. Then the rope was brought into use. The auger was lifted 2 or 3 feet off the bottom of the hole by means of the rope over the pulley, and then was allowed to drop. As soon as the barrel was filled with cuttings, the auger was withdrawn and emptied. It was found that by keeping a small amount of water in the hole, drilling and picking up of samples were facilitated. Two unskilled laborers operated the outfit, one serving as "driller and sample grabber," and the other providing the power in lifting the auger during the process of drilling. This type of rig will be referred to as Type A.

The cores and cuttings thus secured were washed free of mud, then examined for Foraminifera by a geologist. When a sufficient number of fossils for identification was found, the hole was abandoned and the rig moved to a new location.

On the second hole an effort was made to get more leverage in drilling, and a somewhat different plan was devised for raising and lowering the auger. This arrangement will be designated Type B. A 4×4-inch post 8 feet high was erected on a 2×6-inch board 6 feet long as a base. This upright was then braced with 2×4-inch boards to hold it fairly rigid. Two holes were bored through the upright post, one 2 inches and the other 2 feet from the top. A bolt 8 inches long through the upper one of these holes served as an axle for the "walking beam," the latter being a 2×4-inch board twelve feet long. The beam was mounted on the axle at a point 4 feet from one end to give the required leverage in drilling. When the hole was drilled to a depth of about 6 feet in the manner described under Type A, the rope attached to the drop auger was secured to the short end of the beam, with about 4 feet of the rope connecting these two points. Another rope was fastened to the long end of the beam for convenience in operating. The beam was then set in motion, "pump-handle fashion," the long end of the beam describing an arc about 8 feet in length. The auger was thus lifted and dropped a distance sufficient to cut and pick up the shale or sand or whatever material

was penetrated. As drilling continued the length of the rope between the beam and the loop on the auger stem had to be increased. Later this device proved more efficient by mounting the beam on the axle 2 feet from the top of the 4×4-inch upright (Fig. 3).

As work progressed the necessity arose for a bit that would cut thin rock beds more quickly than did the 2-inch ordinary auger. An iron wedge-shaped bit was welded to an iron shaft similar to the "stem" of the drop auger (Fig. 1). Before the loop was made in the upper end of the shaft a 2-inch pipe about 6 feet long was slipped over the shaft and down to the point where the shaft was welded to the wedge. The pipe was then filled with lead to give it weight of about 25 pounds. When rock was encountered this heavy wedge bit was attached to the drilling rope in place of the auger. After the rock was broken up with this tool the auger was again attached and drilling proceeded as before.

ADVANTAGES AND DISADVANTAGES

Of the two types of rig used, Type A gave the better results. Perhaps a little more strength was required in the actual drilling process, but the auger could be withdrawn from the hole more easily when necessary to remove cuttings from the barrel. In the first type there was very little vibration of the derrick, while in Type B some difficulty was encountered in bracing the apparatus and holding it firmly to the ground during drilling. In Type B it was necessary to stop at intervals during drilling to adjust the length of the rope from the short end of the beam to the auger. In Type A this was unnecessary.

The drop auger has advantages over other types of shallow drilling apparatus in the following points: (1) It is inexpensive to build and operate. (2) It is light in weight and therefore easily transported. (3) Almost continuous core was secured in shale, and in some cases small cores of fairly hard sandstone were obtained. (4) Depths of 25 to 50 feet were easily reached and one hole was carried to 93 feet.

The disadvantages observed are as follows: (1) It gives best results only at comparatively shallow depths. (2) It is usually impracticable where hard rock is encountered and where a consider-

able amount of subsurface water enters the hole. In the latter case the cuttings are carried suspended in the water until the mud gets so thick that drilling is very difficult.

COST OF OPERATIONS

With the two types of rig described above, sixty-eight holes were drilled, making a total of 2,254 feet, an average of 33 feet per well. The total expense of the operations including original cost, maintenance of equipment, labor, transportation, and shipping of samples was $503.86, or an average of 22.3 cents per foot. The transportation item was very small, as the rig could be moved in the automobile used by the geologist in charge of operations. About one-third of a barrel of water was supplied daily to each rig. This also could be carried on the geologist's car.

CONCLUSIONS

For the results desired, the drop auger proved to be quite satisfactory. It is recommended for use in territory where comparatively shallow drilling depths are sufficient to reach fresh samples of formations, and where there are no thick hard rock layers or subsurface water-bearing zones to prevent the collection of these samples.

DISCUSSION

ORIGIN OF THE FAULTS IN CREEK AND OSAGE COUNTIES, OKLAHOMA

I have been much interested in Mr. Foley's paper, in the March *Bulletin*, entitled "Origin of the Faults in Creek and Osage Counties, Oklahoma." The author is to be complimented on his manner of dealing with the subject and on the skill with which he has used theoretical and experimental data to orient the strain-ellipse diagram to explain the structure in the area of faults.

Examination of the author's map gives one the impression that there is a remarkable parallelism over the entire area between both the fault belts and the short *en échelon* faults making up the belts. This suggests that he would be justified in placing other strain diagrams in Creek and Okfuskee counties, and perhaps elsewhere, as in Seminole and Lincoln counties, in addition to the single diagram he shows in Osage county. On doing so it would become apparent, on account of the common orientation of the diagrams, that the state of stress existing to an unknown depth within the fault area at the time of faulting was practically uniform throughout.

We might bound this fault area in a general way by an elongated rectangle, approximately 150 miles long and 60 miles wide, with the longer axis trending NNE.–SSW., parallel to the fault belts, and assume that it represents a determined region of uniform state of stress. But is there anything to indicate that the stress uniformity persisted in the rocks bounding the rectangle? It is reasonable to believe that it was these bounding stresses that induced the uniform state within the rectangle, and it is conceivable that these outer stresses may, as a matter of fact, have been of various inclination and sign and still were of such character that their cumulative or resultant effect was to set up uniform stress conditions within the rectangle. This idea, of course, rather begs the issue by suggesting conditions that were more complicated than may be necessary to explain the situation simply, as has been done by the author.

Mr. Foley assumes, I believe, that the outer stresses had the same orientation as the inner, as he has drawn on his map the arrows *A* and *B* on the flanks of the Ozarks and the Granite Ridge, so as to be parallel to the shear line *YY* of the diagram in the fault area. If, however, we are seeking a simple explanation of the causes, would it not be more tenable, in view of the geographical situation of the rectangle with respect to these uplifts, to accept Mr. Thom's views expressed in the discussion and to look for the causal forces or disturbing agencies as originating in the south, as the Ouachita-Arbuckle uplift, rather than the Ozarks?

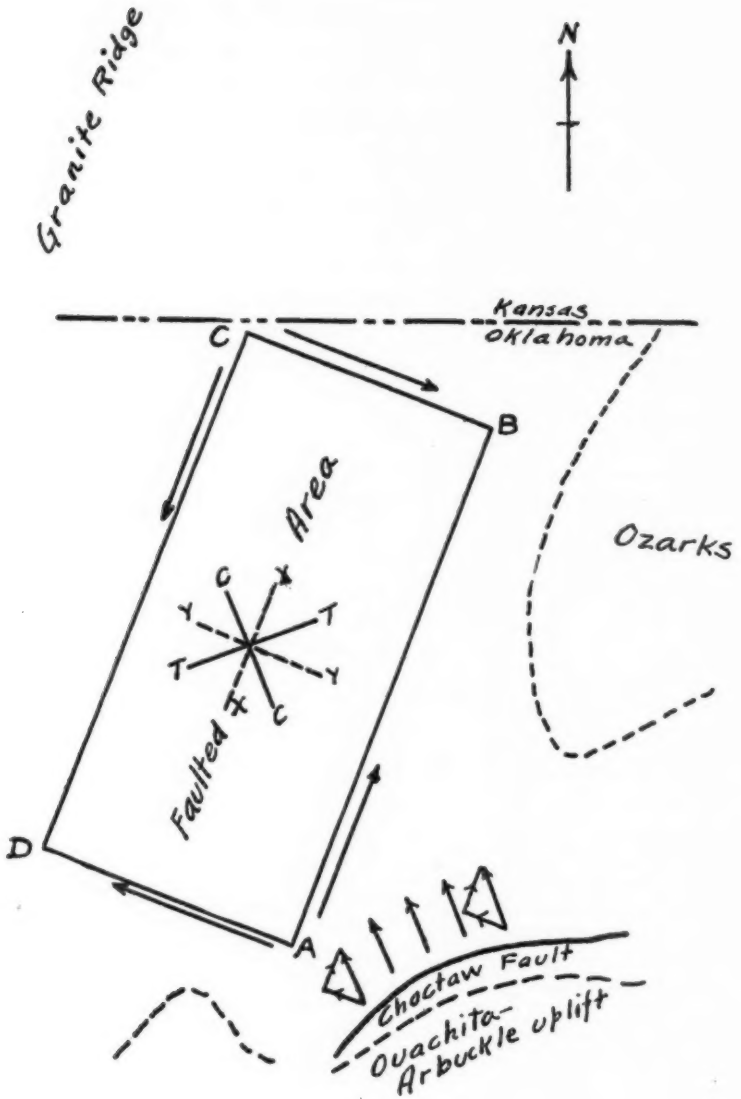
Granite Ridge
N
Kansas
Oklahoma
C
B
D
A
Faulted Area
Ozarks
C
Y
T
T
Y
Y
T
C
Choctaw Fault
Ouachita-
Arbuckle uplift

FIG. 1

To illustrate this idea I am submitting the attached sketch (Fig. 1) based on Foley's map and strain diagram orientation. This is done with considerable diffidence, as I realize clearly the pitfalls open for one venturing on long-range geological speculations such as this. The sketch aims to suggest that the Choctaw fault zone may offer an equally simple explanation of the structure of the fault area. The thrust here might reasonably be assumed to be directed as shown by the arrows. If such a thrust were transmitted into the area of the rectangle its effects there can be analyzed precisely to fit the author's diagram. CC would be the axis of compression, and TT that of elongation, while XX and YY are lines of maximum shear. The concealed faults in the basement complex and harder Paleozoics are thought by Fath and the author to be parallel to the belts of *en échelon* surface faults, that is to be parallel to AB or XX. Both authors imply that these buried faults moved horizontally in such fashion that a fault prism on the east moved northward with reference to the prism on the west, and this movement results in a simple shear. As the shearing stress intensities parallel to AB and AD are of equal value and of maximum strength, we might expect buried faults to have formed not only parallel to AB, but also to AD. The fact that belts of faults on the surface parallel to AD or YY appear to be absent lends weight to the simple shear or rotational strain idea. This apparent rotational effect might possibly be explained as due to the localization of the causal forces near the corner A, or to peculiar elastic or structural features of the harder rocks.

One further suggestion might be made, and that is that the west-dipping monocline mentioned by Foley as extending across the state southward almost to the Arbuckles may be an earlier structure developed by the Ozark uplift, and that at some later period the faults and attendant minor structures were superimposed on the monocline because of activity along the Choctaw fault zone. It seems reasonable, in accordance with the author's views, that the Granite Ridge acted as part of a passive buttress to these movements.

It is to be hoped that Mr. Foley will undertake further investigations along the same lines, as it will be by such efforts that geologists will gain an understanding of the relations of structure to stress and strain.

E. L. Ickes

Sawtelle, California

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

On May 13 and May 20, Mr. L. R. VAN BURGH, of the Department of Internal Revenue, U. S. Treasury, lectured to the students of the departments of Petroleum Engineering and Geological Engineering at the Colorado School of Mines on the subject of "The Valuation of Oil Lands."

W. Z. MILLER, accompanied by Mrs. Miller, spent the months of April and May making investigations of areas in north Arkansas. They were also recent visitors in Pittsburgh, Pennsylvania, and Columbus, Ohio, but have now returned to their home in Tulsa.

R. F. BAKER, chief geologist for The Texas Company at Houston, visited the Shreveport, Louisiana, office May 24 and attended the weekly luncheon of the Shreveport Geological Society at the Washington Hotel.

A. L. WINTER, division geologist for the Atlantic Oil Producing Company at Shreveport, Louisiana, is again at his desk after a short illness in May.

A. D. MILLER has completed a year of post-graduate work under Professor H. V. HOWE at Louisiana State University and has joined the geological staff of the Atlantic Oil Producing Company at Shreveport, Louisiana, in the capacity of paleontologist.

E. G. SINCLAIR, who has recently resigned from his position as geologist in the Production Department of Midwest Refining Company, passed through Tulsa, Oklahoma, June 8, en route to Venezuela to take up duties in the Geological Department of Venezuelan Sun Limited. Mr. Sinclair graduated in geology at Leland Stanford University in 1911.

D. T. RING, consulting geologist, Box 804, El Dorado, Arkansas, has returned from a business trip to Central America.

R. A. RANK, geologist with the Navarro Oil Company, Houston, Texas, stopped in Shreveport, Louisiana, in June, on his way to the Urania field in LaSalle Parish. Mr. Rank's home address is 920 Aganier Ave., San Antonio, Texas.

F. W. GARNJOST, who was appointed receiver of the Caddo Central Oil and Refining Company of Louisiana, Incorporated, and more recently was general manager of the newly organized Crystal Oil Company, Shreveport, Louisiana, returned by automobile, in June, to his home in New York.

I. M. HAWKINS of Lake Charles, Louisiana, a graduate of Louisiana State University, has joined the geological staff of the Louisiana Oil Refining Corporation, Shreveport, Louisiana.

R. W. HARRIS, who has just completed a year of post-graduate work at Louisiana State University, is collecting samples of clays in the vicinity of Shreveport, Louisiana, for John W. Whittemore, state ceramic engineer, who is conducting an investigation of the clays of the state.

THE SHREVEPORT GEOLOGICAL SOCIETY held its annual outcrop trip this year, June 12 and 13. About sixty members and visitors, including representatives from Arkansas, Oklahoma, and Texas, made up the automobile party that left Shreveport Saturday morning, June 12, after a preparatory lecture the preceding evening by H. V. HOWE, who has been conducting a series of lectures before the society throughout the year. They visited typical Tertiary exposures in north-central Louisiana, including the Wilcox, Claiborne, Jackson, and Vicksburg formations. The party stayed at Alexandria Saturday night and completed the trip by returning to Shreveport Sunday night. Problems under discussion were the detailed differentiation and identification of newly recognized formations in the Claiborne group and their correlation with similar beds in the adjoining states of Mississippi and Texas. W. C. SPOONER took moving pictures of the party at different places on the trip. The committee in charge of this year's excursion consisted of C. L. MOODY, chairman, M. W. GRIMM, and N. G. WINTER.

R. E. SOMERS has been made head of the department of geology of the University of Pittsburgh. ROSWELL H. JOHNSON continues as head of the department of oil and gas production.

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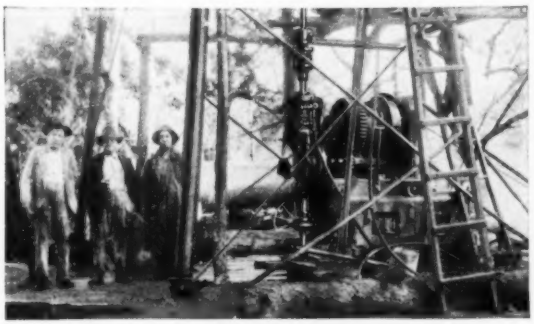

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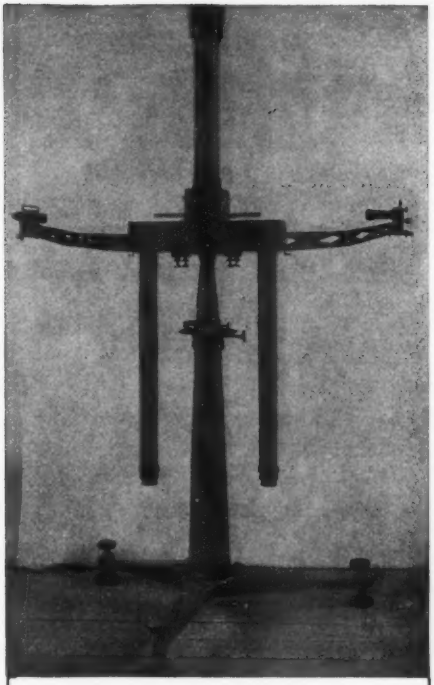

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